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Project Engineer - James Rippin - ASRNCF-3

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~~28 February~~ 1963

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1. RADIATION FROM PERIODIC STRUCTURES

1.1 Purpose

The purpose of this investigation is to explain the observed properties of log-periodic antennas through experimental and analytical investigation of their uniform periodic counterparts.

1.2 Factual Data

1.2.1 Research Staff - Paul G. Ingerson, P. E. Mayes

1.2.2 Status

Radiation patterns measured at frequencies in the stop-bands of the uniform periodic dipole array are not readily predicted in all cases from the Brillouin diagrams previously measured. To better explain this result, attempts have been made during this period to measure the currents in each element of the array. The reduced sensitivity of the current probe and exact positioning of the probe relative to the elements have presented problems in making these measurements accurately. However, it has been found that adequate sensitivity can be obtained by using a Rohde and Schwarz Diagraph to make the phase measurements. An improved mount for positioning the current probe has been constructed.

1.3 Plans for the Next Interval

Amplitude and phase of the element currents will be measured with the improved system. Radiation patterns will be calculated from these near-field data and compared with the backfire patterns observed in the stopband.

2. LOG-PERIODIC CAVITY-BACKED SLOT ANTENNAS

2.1 Purpose

This work is being directed toward the development of a log-periodic array of cavity-backed slots which will produce vertically polarized radiation without having the structure projecting above the ground plane.

2.2 Factual Data

2.2.1 Research Staff - V. A. Mikenas and P. E. Mayes

2.2.2 Status

This project is being carried on in an effort to apply some of the more recent concepts in log-periodic antenna development to the design of flush-mounted cavity-backed antennas by introducing π radians phase shift between adjacent resonant cavities. An analogous type of performance to that of the log-periodic dipole array is anticipated. In other words, it is expected that due to the presence of periodically placed resonant cavities, the system would possess stopbands in which vertically polarized backfire radiation would occur. As was noted in the last quarterly report, a single cavity was constructed and several feed loops were employed in an attempt to evaluate the effects of the loop on the impedance locus versus frequency. It was found that the input impedance locus versus frequency for a single cavity resembled the input admittance locus of a dipole and, as a result, the cavity system may be considered to be a dual of the dipole array.

Having obtained sufficient data for a single cavity, a log-periodic cavity system was designed and constructed. The choice of parameters for the design involved many considerations and existing information on the dipole array was used. A scaling factor of $\tau = 0.85$ was used in the design. A total number of 10 cavities were included in the system with dimensions ranging from L = 9.65 cm, H = 4.82 cm, W = 2.57 cm to L = 41.6 cm, H = 20.8 cm, W = 11.1 cm. (See Figure 2.1). With these choices of parameters, the cavity system is expected to operate in the frequency range of 400 Mc to 1200 Mc which will therefore have a relative bandwidth of 3:1. It was decided to employ printed circuit techniques for the construction of the loop in order to attain as much accuracy and uniformity as possible.

A new aperture plate holder 7 ft. x 6 ft. in size was constructed during this quarter. It was so designated as to hold aperture plates made to fit the new Scientific-Atlanta ground screen. It is mobile and may therefore be

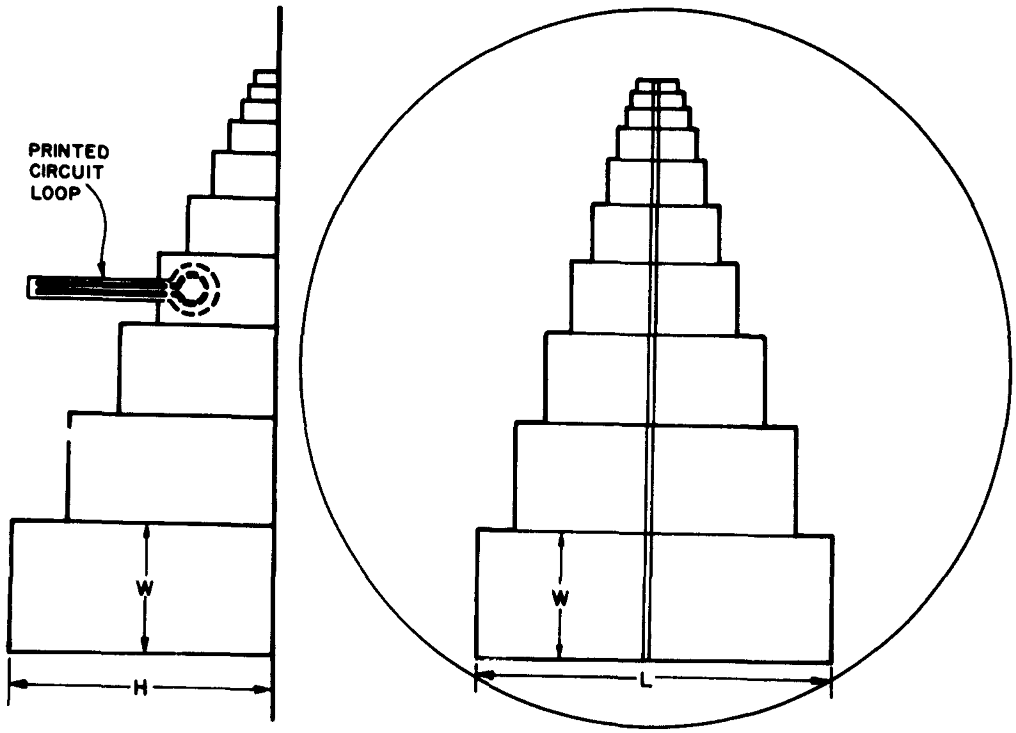


Figure 2.1. Cavity-backed slot antenna showing one printed circuit loop.

used in any absorbing chamber available at the time. The aperture plate holder will be used primarily for impedance measurements of antennas and at the present time is being employed for impedance measurements of the flush-mounted cavity backed antenna system.

Impedance measurements were at first restricted to a single cavity. The apertures of the other cavities were covered with aluminum foil to avoid any perturbations. The purpose of this was to ascertain the performance of a printed circuit loop. A typical impedance locus versus frequency is seen in Figure 2.2 for a cavity of dimensions L = 18.45 cm, H = 9.23 cm, W = 4.92 cm and the aperture being completely open. At the present time, scaled loops are being built for the other cavities and tests are being made to show the frequency scaling.

2.3 Plans for the Next Interval

All the loops will be connected in series and impedance loci and radiation patterns will be determined for the entire structure.

It is expected that a uniform periodic array will be constructed from which near field measurements will be made, thereby determining the Brillouin diagram for the structure.

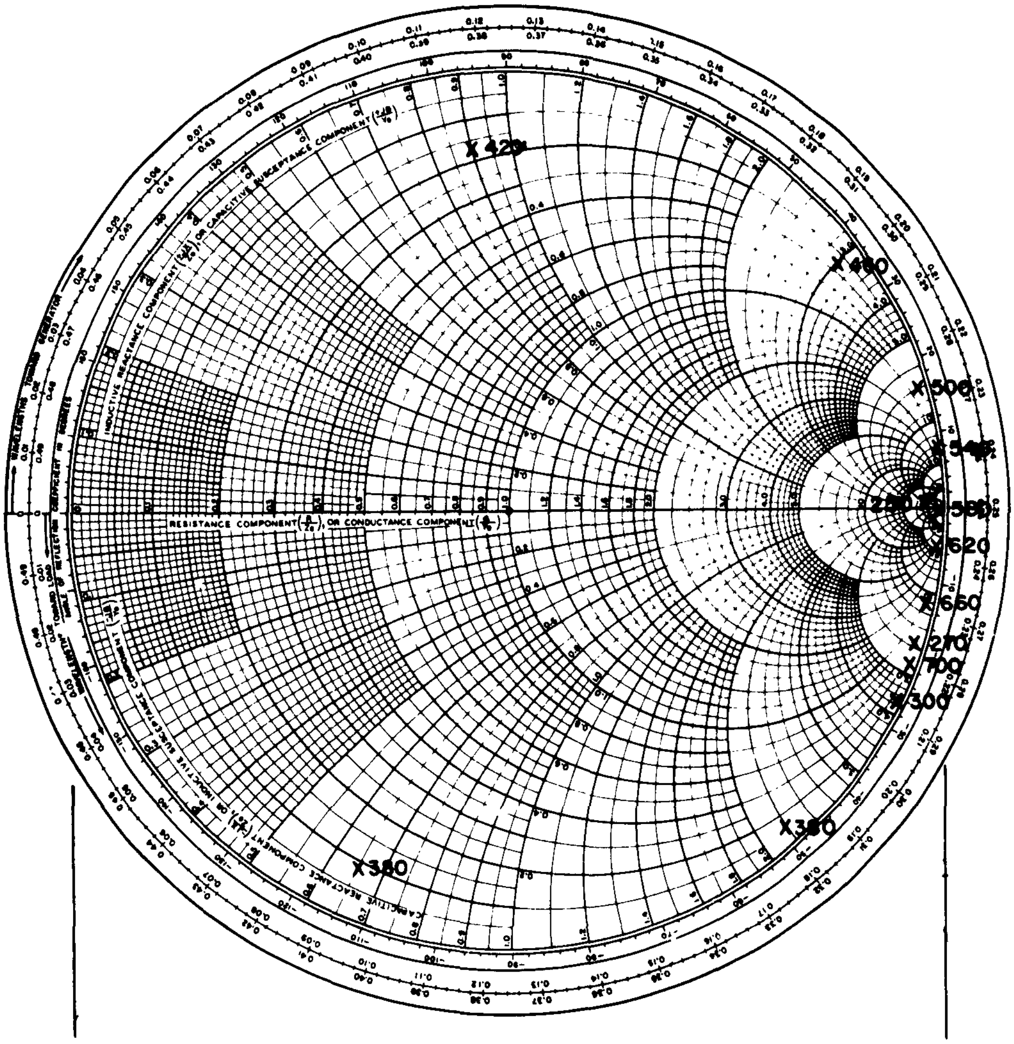


Figure 2.2 Impedance locus versus frequency in Mc referred to the input of the printed circuit loop.

3. LOG-PERIODIC MAGNETIC-CURRENT ANTENNAS

3.1 Purpose

The purpose of this work is to investigate an LP array of magnetic dipole elements.

3.2 Factual Data

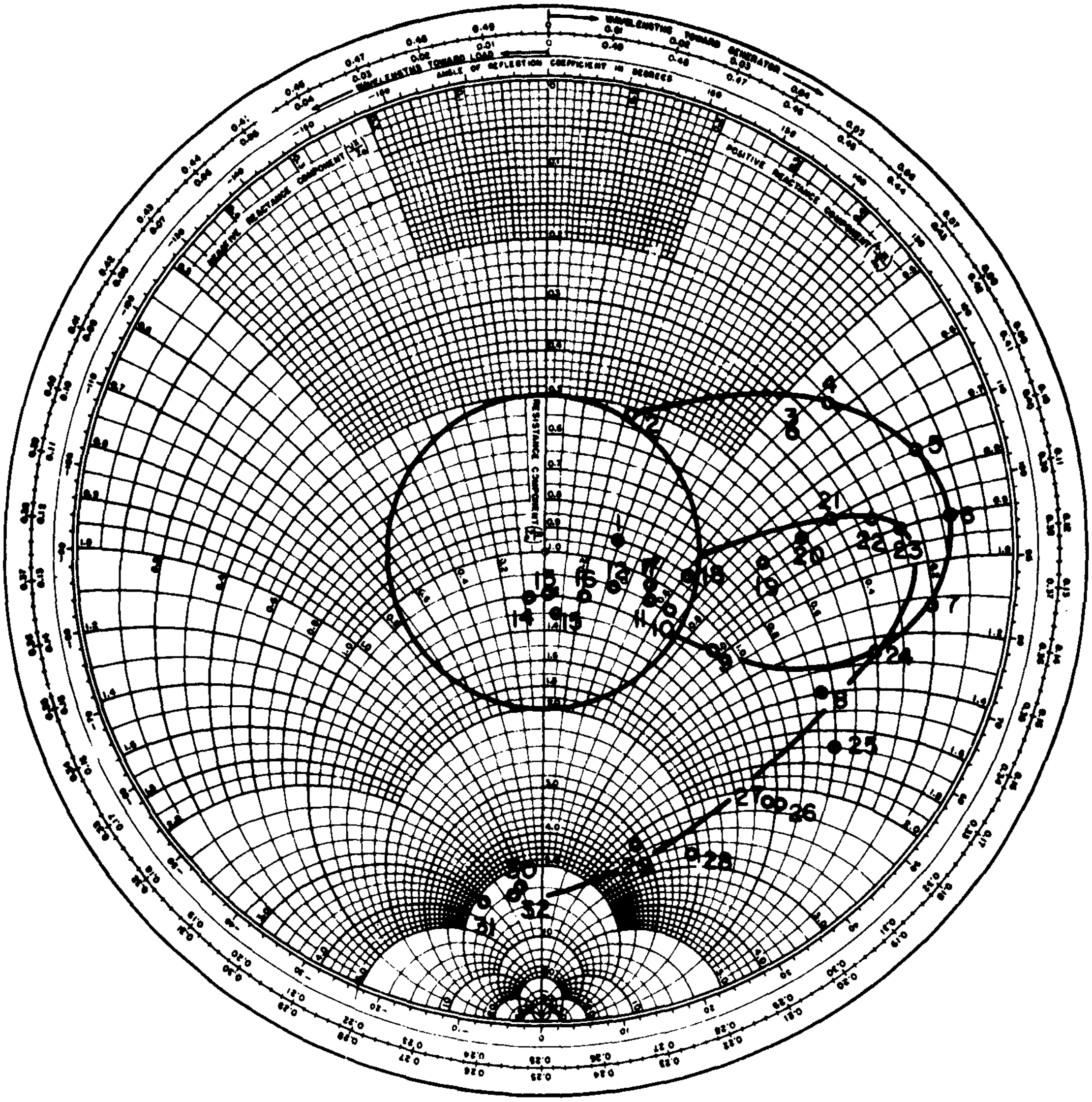
3.2.1 Research Staff - P. E. Mayes

3.2.2 Status

The impedance of the conical slot antenna has been measured on the 300-ohm Lecher wire system. The results are plotted in Figure 3.1. The VSWR falls below 2:1 in the band from 460 to 580 Mc. This band is considerably narrower than that where the patterns were very good (400-800 Mc as shown in Quarterly Report No. 1). There is an indication, however, that the impedance is again approaching a real value of approximately 300 ohms near 360 Mc. This is near the low frequency cutoff of the antenna, however, and further deviations in the impedance locus would probably be due to end effects. A new antenna has been built which has more elements and should make it possible to study the impedance over a wider frequency range. Preliminary results on this antenna show periodic deviations in impedance from the real value of about 300 ohms. These impedance variations seem also to be accompanied by pattern deterioration.

3.3 Plans for the Next Interval

Further measurements on the new antenna will be made in an effort to determine the cause of the impedance variations.



Points	Frequency	Points	Frequency	Points	Frequency
1	360.4 Mc	12	496.7 Mc	23	684.6 Mc
2	371.0	13	571.4	24	704.86
3 3	382.0	14	526.5	25	725.72
4	393.3	15	542.1	26	747.2
5	405.0	16	558.2	27	769.3
6	416.95	17	574.7	28	792.1
7	429.3	18	591.7	29	815.5
8	442.0	19	609.2	30	839.64
9	455.0	20	627.23	31	864.50
10	468.5	21	645.8	32	890.
11	482.4	22	664.9		

Figure 3.1. Input impedance of the conical slot antenna referred to 300 ohms.

4. LOG-SPIRAL ANTENNAS

4.1 Purpose

The objective of this investigation is to study the characteristics of present forms of the logarithmic spiral antennas and investigate new versions of the antenna.

4.2 Factual Data

4.2.1 Research Staff - J. D. Dyson

4.2.2 Status

As outlined in prior reports an intensive investigation is being made of the amplitude and phase characteristics of the near fields on the conical log-spiral antennas. The consideration of the conical logarithmic structure to be locally periodic with slowly varying parameters allows this experimental data to be analyzed in terms of prior work on the cylindrical monofilar and bifilar helix.

The amplitude of the near fields measured along the surface of one antenna is shown for several frequencies of operation in Figure 4.1. These data were recorded with the plane of the loop positioned parallel to the arms and then moved along a line parallel to, and 1 cm away from the surface of the arms. The amplitude is plotted as a function of the radius of the cone in wavelengths.

At frequencies such that the antenna scales properly, there is a region of tightly bound waves near the tip of the antenna. As a/λ increases these fields become more loosely bound and hence couple more strongly to the probe until a region is reached, "a" greater than .105 λ, where there is a rapid decay of these fields due to radiation. It is reasonable to assume that energy is lost in radiation before this decay is evident on the measured data and calculations are being made of the far field, based on near field data, in an attempt to determine the effective width of the active region. At present it may be assumed that the effective active region extends from a minimum radius such that the amplitude is approximately 2 db below the peak amplitude, to a maximum radius such that the amplitude has decayed 20 db below this peak amplitude. Thus for this antenna, this region is defined to such that $.09 \leq a/\lambda \leq .24$. or, it extends from approximately a diameter of .2 wavelengths to .48 wavelengths.

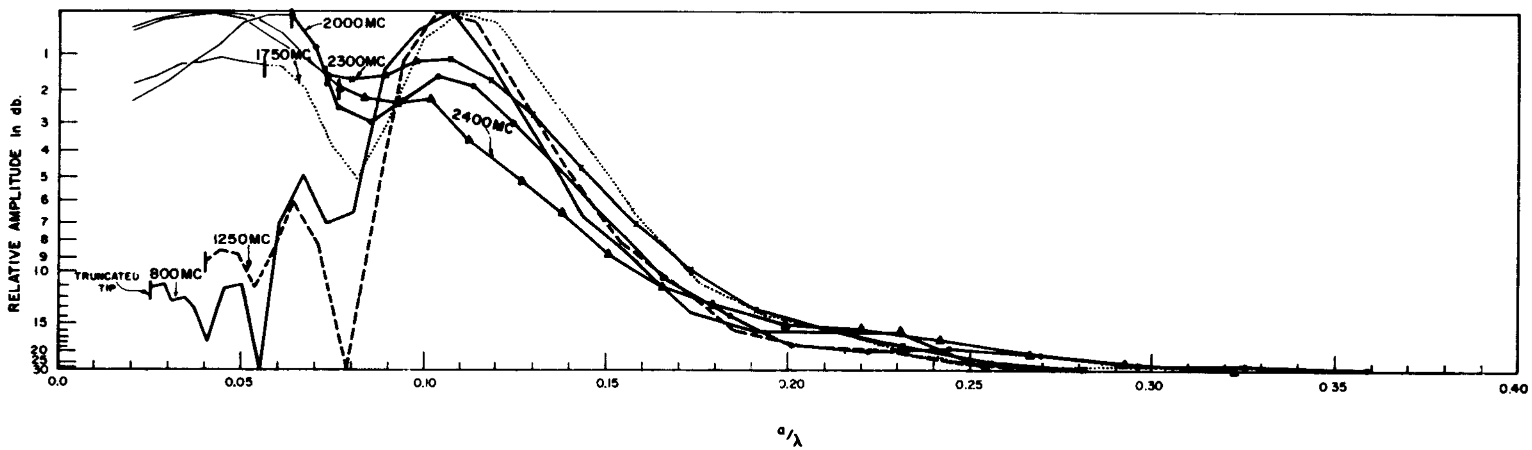


Figure 4.1. Near field along one conical log-spiral antenna measured with a shielded loop. $\alpha = 83^{\circ}$, $\theta_o = 10^{\circ}$ constant width arms.

In addition to this actual region, there must be sufficient structure ahead of this region to properly establish the desired fields on the antenna. This is clearly indicated in the experimentally determined Brillouin diagrams for these antennas and in the amplitude curves of Figure 4.1. At 2000 Mc where the truncated tip is approximately .125 wavelengths in diameter the character of the fields in the active region has changed. A portion of this change is attributable to the fact that at these frequencies the probe is getting to be larger and also farther away, in terms of wavelengths, from the surface of the structure. Corrections for these factors will be taken into account in future measurements.

4.3 Plans for the Next Interval

This study will be continued and extended to antennas with other parameters.

5. LOG-PERIODIC ZIGZAG ANTENNAS

5.1 Purpose

This work is directed toward obtaining design information about a class of periodic leaky wave structures which are potentially high-gain, frequency-independent antennas.

5.2 Factual Data

5.2.1 Research Staff - P. E. Mayes

5.2.2 Status

Impedance measurements on the balanced log-periodic zigzag antennas have been continued. Frequencies below 1000 Mc have been used to alleviate the problem of construction tolerances, but methods of mounting these large antennas and the two-wire feeder without affecting the measurements have been troublesome. A series of impedance measurements was rerun after removing part of the wooden supports used on previous models. The results were somewhat modified from those obtained previously. Additional work is needed to evaluate whether the changes were within the range of repeatability of the system. The new measurements were made using the indoor anechoic chamber.

The results of the measurements to date using the new system are summarized in Table I. (See Quarterly Report No. 4, AF33(657)-8460, for a definition of parameters).

Table I

Impedance of Balanced Log-Periodic Zigzag Antennas

Antenna	τ	α	ψ	β	z_o (ohms)	Max. VSWR
LPZZ-6	0.9	7.5^o	15^o	5.67^o	215	2.8
LPZZ-7	0.9	7.5^o	15^o	7.5^o	267	2.7
LPZZ-8	0.9	7.5^o	15^o	3.0^o	254	2.8

The conductor width was varied on the above antennas to check the effect on pattern and impedance. The principal effect noted above is a shift in impedance level with little change in the maximum VSWR. Average E-and H-plane half-power beamwidths are between 30 and 40 degrees for the antennas listed in Table I.

Some difficulties have been experienced in making accurate models which would operate without variations in patterns at the high frequencies (above 500 Mc) where the pattern range is satisfactory. These difficulties have been overcome to some extent by using printed circuit techniques to construct the zigzag conductors.

5.3 Plans for the Next Interval

Pattern and impedance measurements on the balanced zigzags will be continued with new antennas with different parameters. An impedance model with $\tau = 0.9$, $\alpha = 5^{\circ}$, $\beta = 3^{\circ}$ has been constructed. Plans are being made for a new pattern range at the new Antenna Laboratory site. An attempt will be made to design the range to operate down to 100 Mc so that patterns and impedance can both be measured on the same antenna model, thus shortening testing time.

6. AN INTEGRATED ANTENNA AMPLIFIER

6.1 Purpose

This investigation will concern the feasibility of utilizing varactor diodes in a backfire antenna to produce amplification in the antenna itself and thereby improve signal-to-noise performance.

6.2 Factual Data

6.2.1 Research Staff - P. G. Ingerson, P. E. Mayes

6.2.2 Status

A design has been chosen for a log-periodic dipole array to be used in a distributed parametric amplifier. The parameters of the array are $\tau = .95$, $\alpha = 10^{\circ}$. Dimensions have been selected which should permit the array to operate from 300 Mc to 500 Mc. It is planned that the pump and idler signals will propagate on a separate slow-wave line formed by a zigzag conductor between the two-wire feeder of the dipole array. For this reason flat rectangular bars have been used in making the dipole array. The phase velocity along the dipole array has been calculated using Carrel's results.* Several zigzag lines have been constructed and are presently being tested.

6.3 Plans for the Next Interval

After the proper phase velocity has been obtained along the zigzag line, varactor diodes will be inserted between the signal and pump lines and new measurements made to determine their effect upon the phase velocity. Pump input and output circuits and idler termination circuits will be devised and the integrated system checked for gain.

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*R. L. Carrel, "Analysis and Design of the Log-Periodic Dipole Antenna", Technical Report No. 52, AF33(616)-6079, October 1, 1961, Antenna Laboratory, University of Illinois, Urbana, Illinois.

7. WAVE PROPAGATION ALONG HELICAL CONDUCTORS

7.1 Purpose

To understand the behavior of the tape helix it is sometimes useful to study the sheath helix which is a mathematical model with an anisotropic cylindrical current sheet.

The determinantal equation for the sheath helix has been derived by others and the real Brillouin (k-β) diagram found. From the k-β diagram people have explained, more or less satisfactorily, many properties of the helix when used as a waveguide in a traveling wave tube or as an antenna.

In this report the solution of the determinantal equation for complex-valued phase constant as well as real-valued phase constant will be exhibited, and the relationship of the solutions for the sheath helix to the solutions for the tape helix, which were previously reported, will be discussed.

7.2 Factual Data

7.2.1 Research Staff - P. Klock, R. Mittra

The determinantal equation for the sheath helix is

$$\frac{(\tau^2 a^2 - n\beta a\ \mathrm{ctn})^2}{k^2 a^2 \tau^2 a^2 \mathrm{ctn}^2\psi} = - \frac{I_n^{1}(\tau a) K_n^{1}(\tau a)}{I_n(\tau a) K_n(\tau a)} \tag{7.1}$$

$$\tau^2 = \beta^2 - k^2$$

If use of

$$I_n(x)K_n(x) = -\frac{x^2}{4n^2}\left[I_{n-1}K_{n-1} + I_{n+1}K_{n+1} - I_{n-1}K_{n+1} - I_{n+1}K_{n-1}\right]$$

$$I_n^{1}(x)K_n^{1}(x) = -\frac{1}{4}\left[I_{n-1}K_{n-1} + I_{n+1}K_{n+1} + I_{n+1}K_{n-1} + I_{n-1}K_{n+1}\right]$$

and the change of variable $\beta = \beta^1 + \frac{n\ \mathrm{ctn}\ \psi}{a}$ is made, then the following equation is obtained

$$\frac{\beta^{12} - \dfrac{k^2}{\sin^2\psi}}{k^2 \operatorname{ctn}^2 \psi} = \frac{I_{n-1}K_{n-1} + I_{n+1}K_{n+1} - 2\, I_n K_n}{2 I_n K_n} \tag{7.2}$$

with the arguments of the Bessel functions

$$\left(\beta^2 - k^2\right)^{1/2} a$$

If

$$\beta^1 = \bar{\beta}^1 \frac{\operatorname{ct}\psi}{a} \quad \text{and} \quad k = \bar{k}\, \frac{\operatorname{ctn}\psi}{a}$$

then Equation (7.2) becomes

$$\frac{\bar{\beta}^{12} - \dfrac{\bar{k}^2}{\sin^2\psi}}{\bar{k}^2 \operatorname{ctn}^2\psi} = \frac{I_{n-1}K_{n-1} + I_{n+1}K_{n+1} - 2\, I_n K_n}{2\, I_n K_n} \tag{7.3}$$

with the arguments

$$\left[\left(\bar{\beta}^1 + n\right)^2 - \bar{k}^2\right]^{1/2} \operatorname{ctn}\psi$$

Equation (7.3) is recognized as being related to simplified Equations (7.1) and (7.2) for $n = -1$ and -2 respectively in the previously reported work on the tape helix.

The relation being that the denominator on the right hand side of Equation (7.3), the factor 2 In Kn, was replaced by a constant A for the simplified equations.

It should be recalled that the general character of the solution for the tape helix in certain regions was shown by the simplified equations.

Figure 7.1 shows the complete k-β diagram for the sheath helix determinantal equation for $n = -1$. Note that there exist multiple solutions and in addition there are solutions corresponding to both determinations of the square root in the argument of the IK products.

Let $\bar{k}_{c1}$ be the smallest value of $\bar{k}$ such that the solution for corresponding to Mode 1 has non-zero imaginary part. The complex-valued solutions for Mode 1 for $\bar{k} > \bar{k}_{c1}$ may be used to explain the backfire characteristics of an antenna and these solutions behave similar to the solutions for the tape helix.

It should be noted that no solution $\bar{\beta}_r^{\,1} = 1 + k$, $\bar{\beta}_i = 0$ was found as has been claimed by Watkins[1] for the approximate determinantal equation for the sheath helix.

In Figure 7.2 the results for $n = -2$ is given for the sheath helix. As in the study of previous equations it was necessary to change brances of the square root so that there exist continuous solutions across the lines $\beta_r = 2 + k$. The solutions for the sheath helix correspond to the solutions for the tape helix near $\beta_r = 2$.

It is suggested that since the complex-valued solutions for the sheath helix give some indication of what to expect for the solutions of the tape helix, that the complex-valued solutions be found for a sheath helix with a concentric perfect conducting cylinder. The determinantal equation has been formulated and a study could be made to indicate how the inner cylinder diameter would affect the complex-valued solution and consequently the behavior of the helix as an antenna about a metallic cylinder.

7.3 Plans for the Next Interval

A study will be made of the determinantal equation for the bifilar tape helix fed out of phase. It is anticipated that this study will enable one to predict the behavior and the characteristics of the bifilar helical antenna.

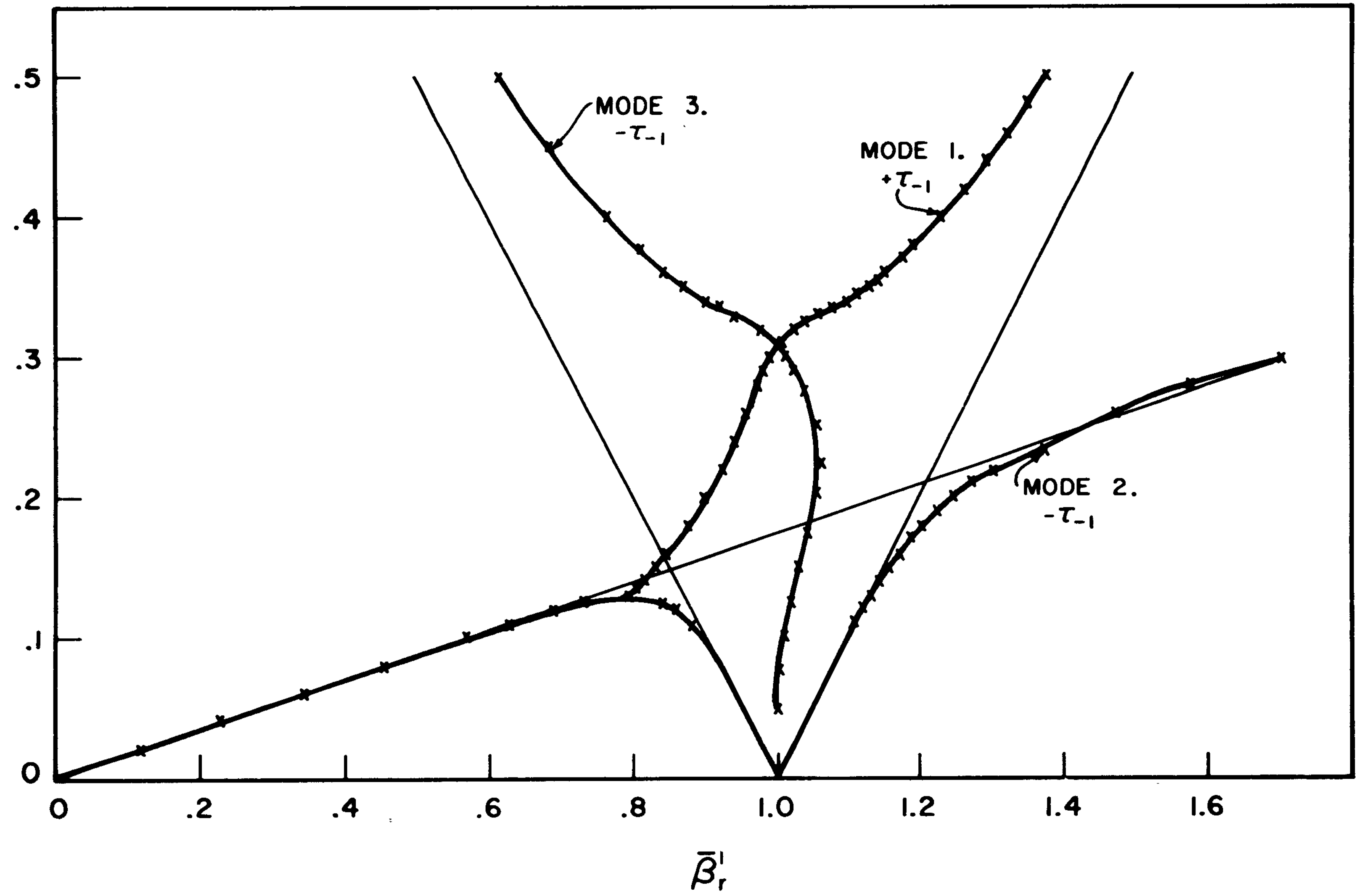
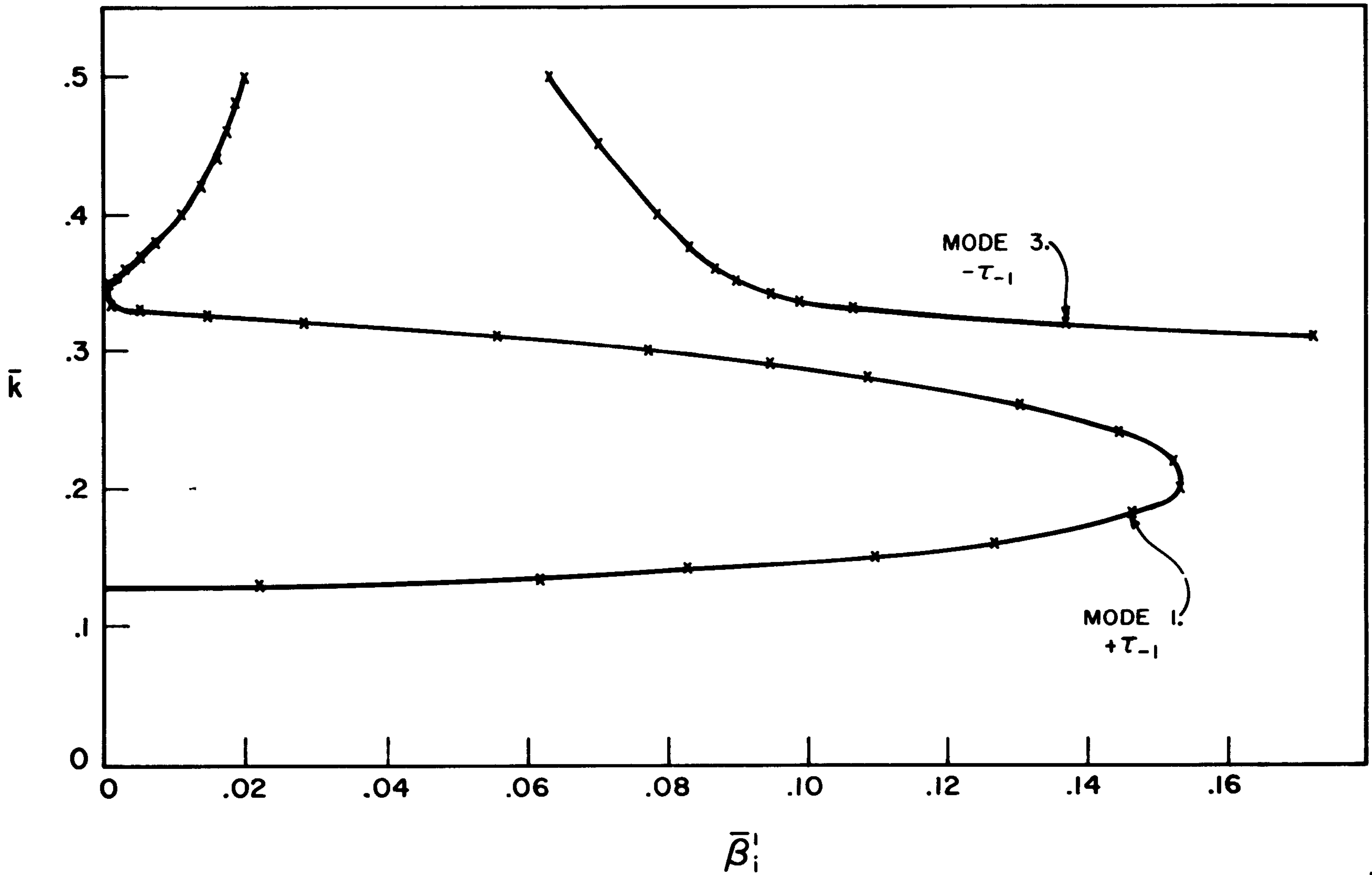

MODE 3.
$-\tau_{-1}$
MODE 1.
$+\tau_{-1}$
MODE 2.
$-\tau_{-1}$
.5
.4
.3
.2
.1
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
$\bar{\beta}_r^1$

Figure 7.1a



MODE 3.
$-\tau_{-1}$
MODE 1.
$+\tau_{-1}$
.5
.4
.3
.2
.1
0
$\bar{k}$
0
.02
.04
.06
.08
.10
.12
.14
.16
$\bar{\beta}_i'$

Figure 7.1b

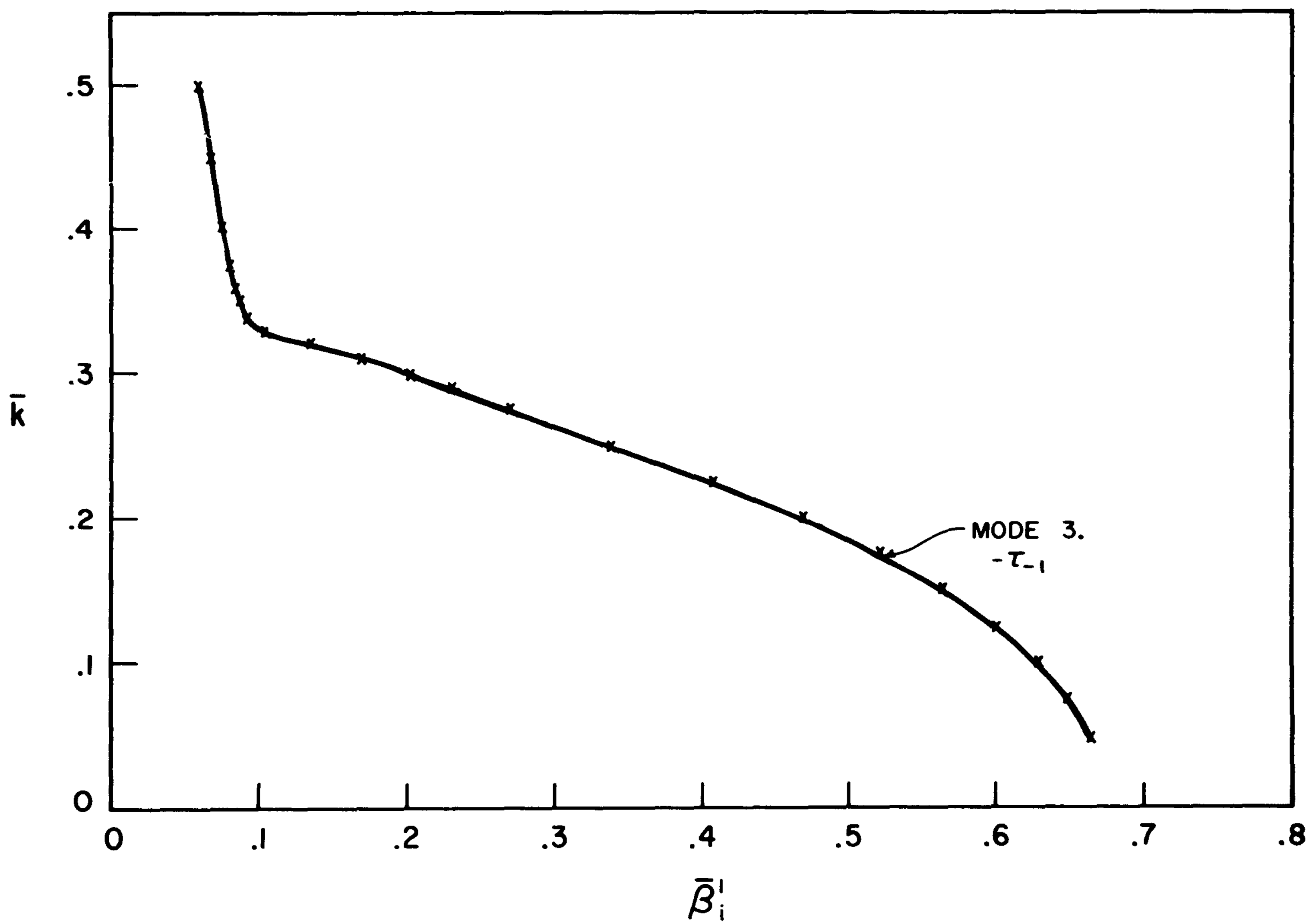


Figure 7.1c

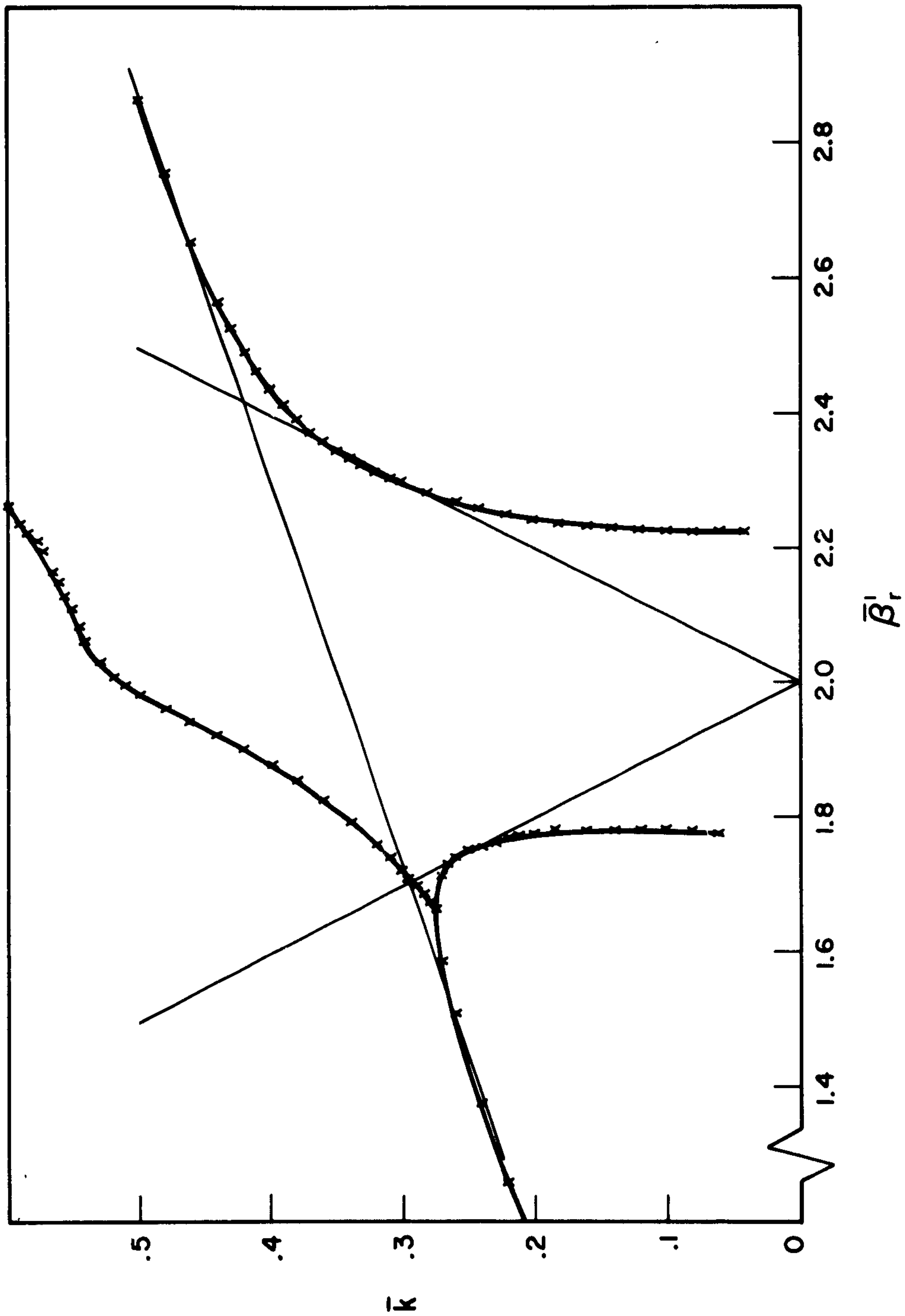


Figure 7.2a

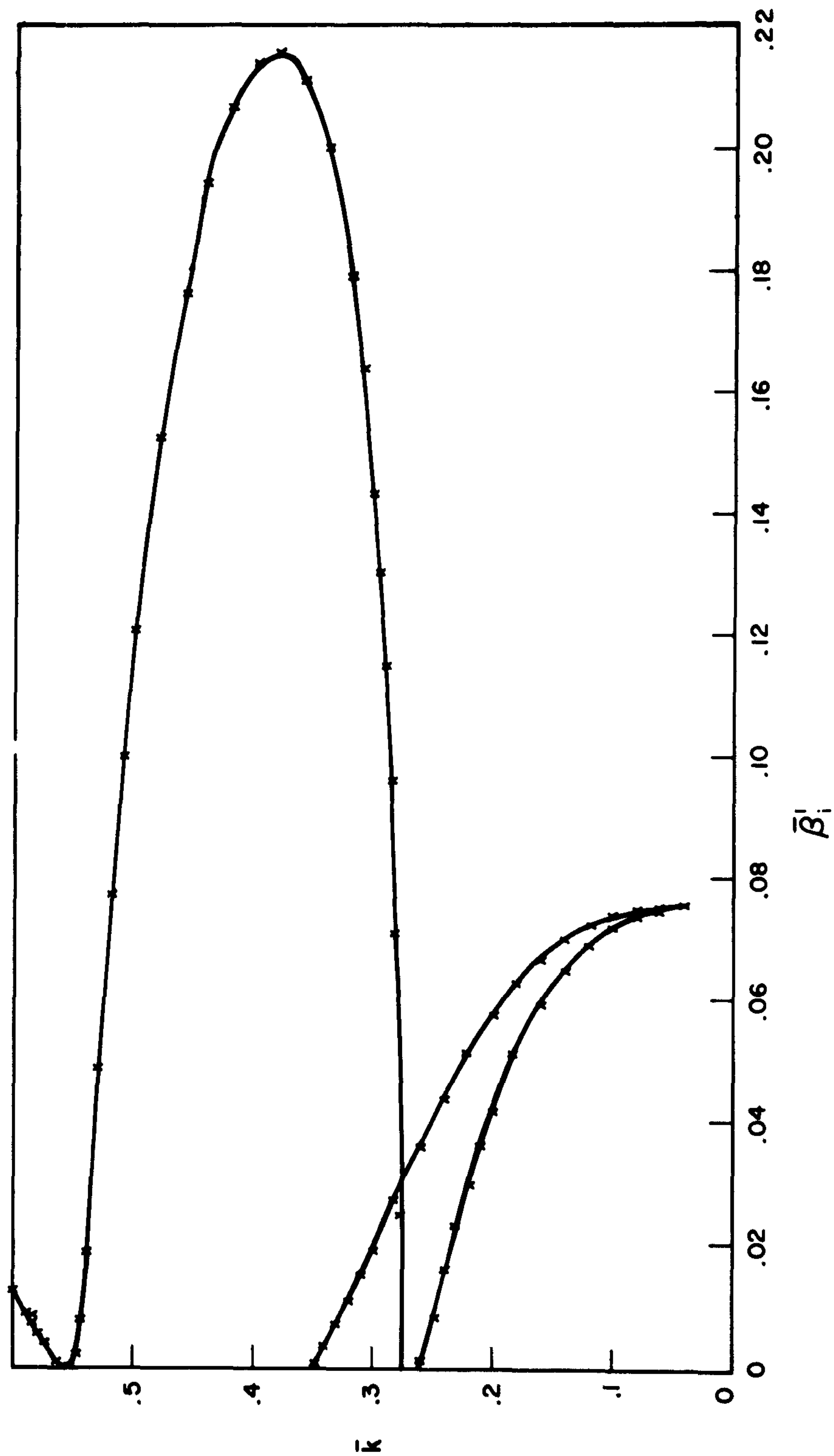


Figure 7.2b

8. INVESTIGATION OF A CLASS OF PERIODIC STRUCTURES

8.1 Purpose

The purpose of this project is to study a class of tapered periodic structures for wide-band applications.

8.2 Factual Data

8.2.1 Research Staff - S. Laxpati, M. Wahl, R. Mittra

8.2.2 Status

We shall continue to report in the format used in the last quarterly report and divide up the report in this section into six sub-sections as follows:

(a) Study of Uniform and Log-Periodically Loaded Transmission Line

A paper entitled "Theoretical Brillouin (k-β) Diagrams for Monopole and Dipole Arrays and Their Application to Log-Periodic Antennas" has been sent in for publication in the IEEE Convention Record. The paper summarizes the work done so far on the study of dipole loaded transmission line. It reports the theoretical k-β diagrams for these structures and compares the results with the experimentally reported ones published by Mayes and Ingerson. The results of the periodic structures are also applied to the LP case and good correlation is obtained with Carrel's experimental and theoretical curves of the voltage amplitude and phase along the transmission line of the LP array.

No further work on this project is planned for the near future.

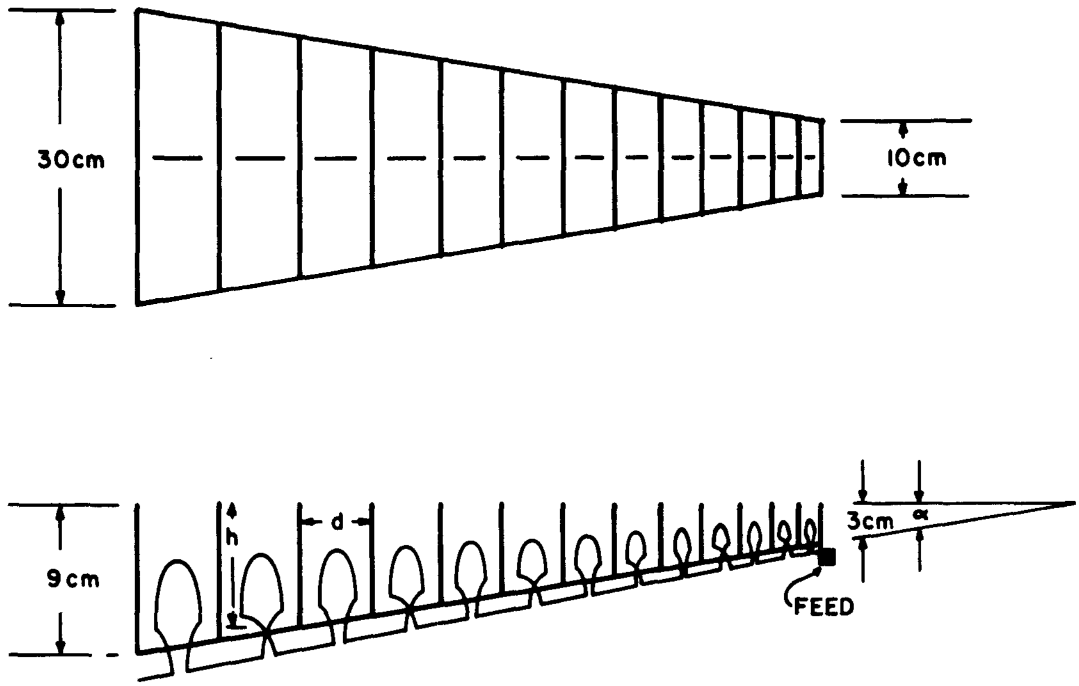
(b) Investigation of Uniform and Tapered Surfaces

The Letter-Rack Antenna has been tested over a wide frequency band and has been found to possess fairly satisfactory pattern bandwidth. A schematic of the antenna with dimensions for a particular model is shown in Figure 8.1. The far-field patterns of the antenna are shown in Figure 8.2. One of the interesting observations about the pattern is that the low frequency limit of the pattern bandwidth (about 500 Mcs) is considerably lower than the frequency at which the largest trough is quarter wave which is 870 Mcs. This phenomenon has been explained by invoking the coupled-mode theory approach.

(c) Waveguide with Glide Reflection Symmetry.

The modulated waveguide structure under investigation is shown in Figure 8.3.

To obtain the determinantal equation for propagation constant β, expansion of the electric and magnetic fields inside and outside the slot, analogous to



THE L.P. LETTER RACK ANTENNA

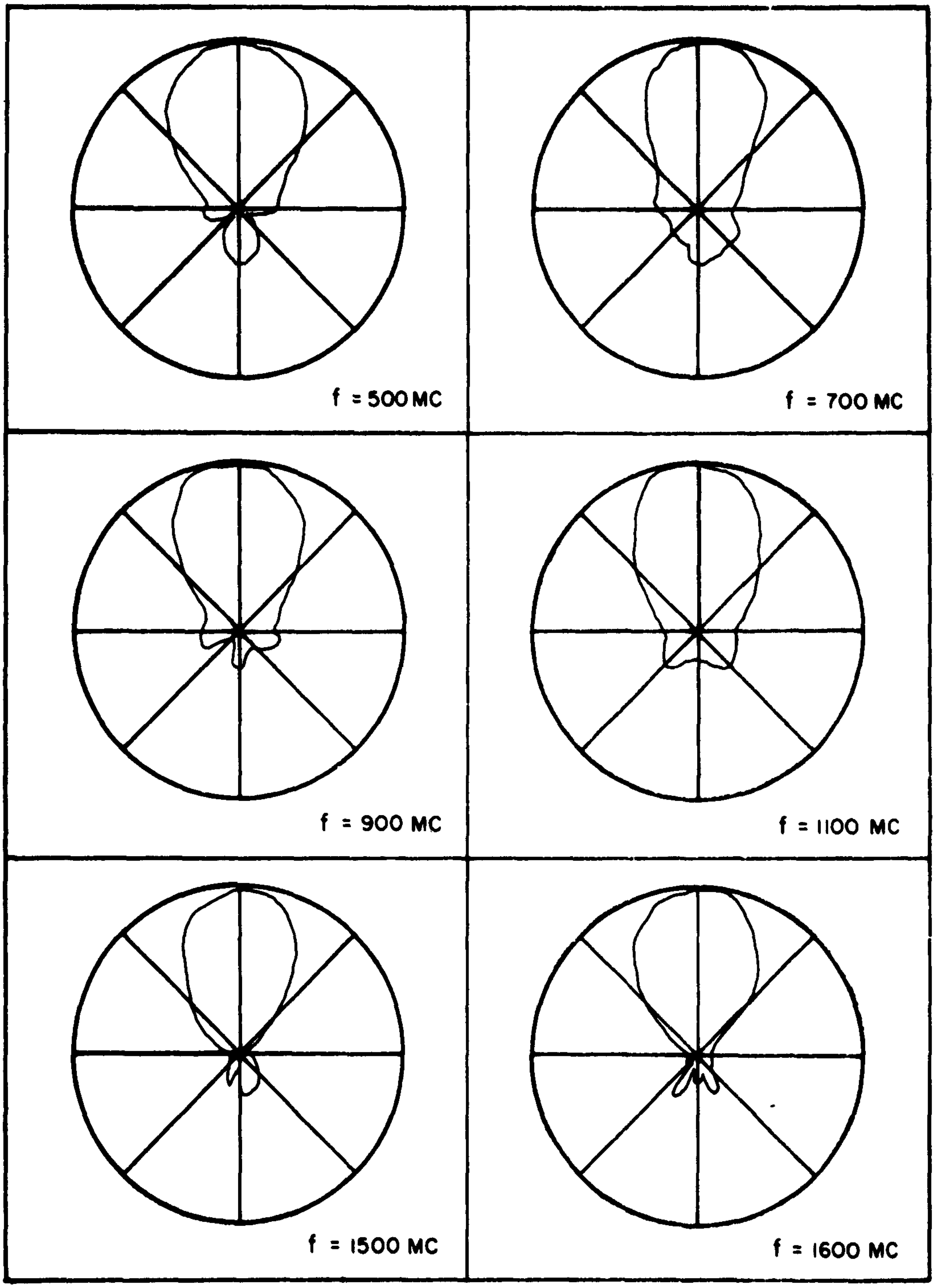
LAST SLOT IS $\lambda/4$ AT 850 MC

τ = .97

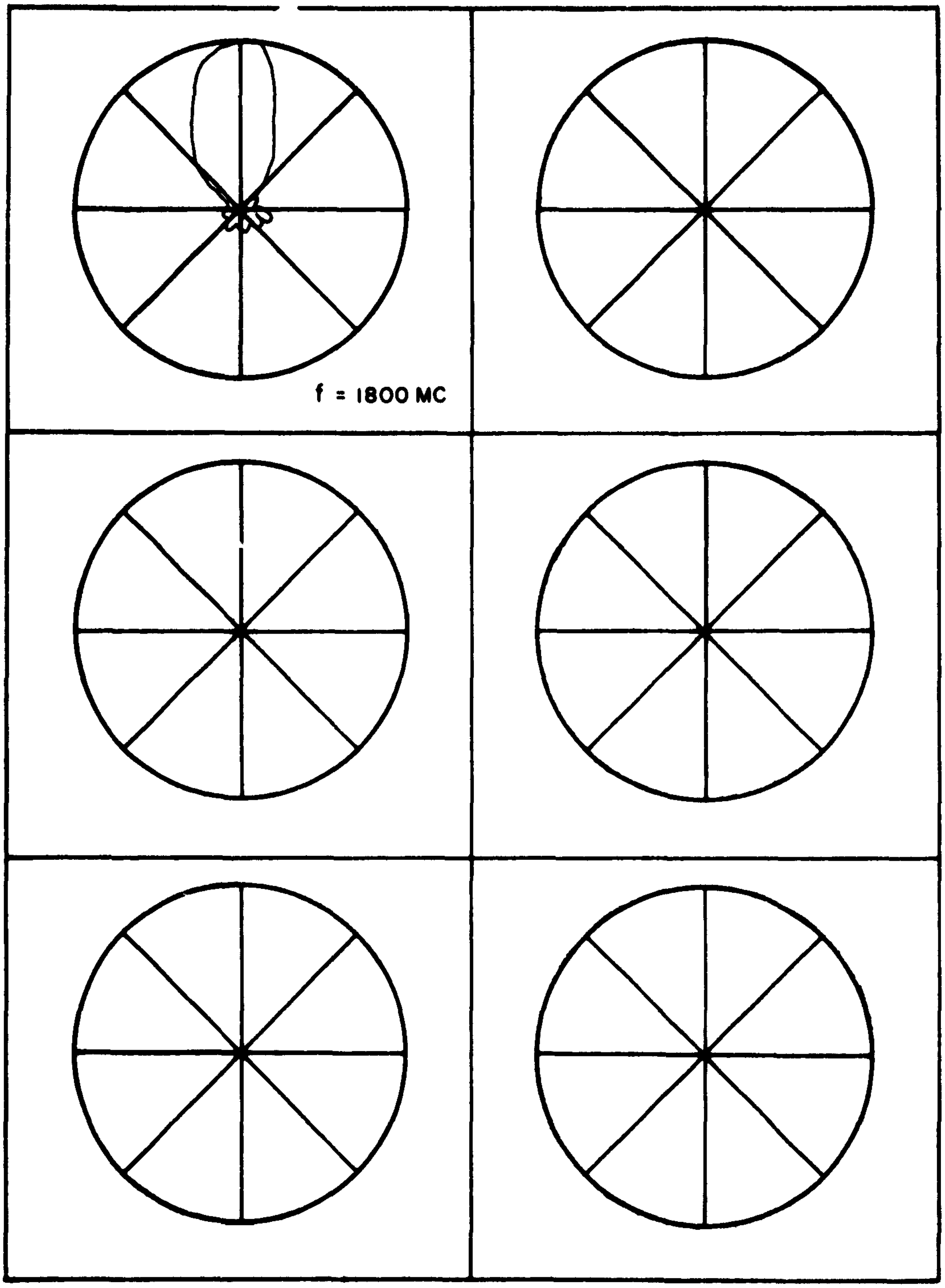
h/d = $4.5/1$

37 ELEMENTS

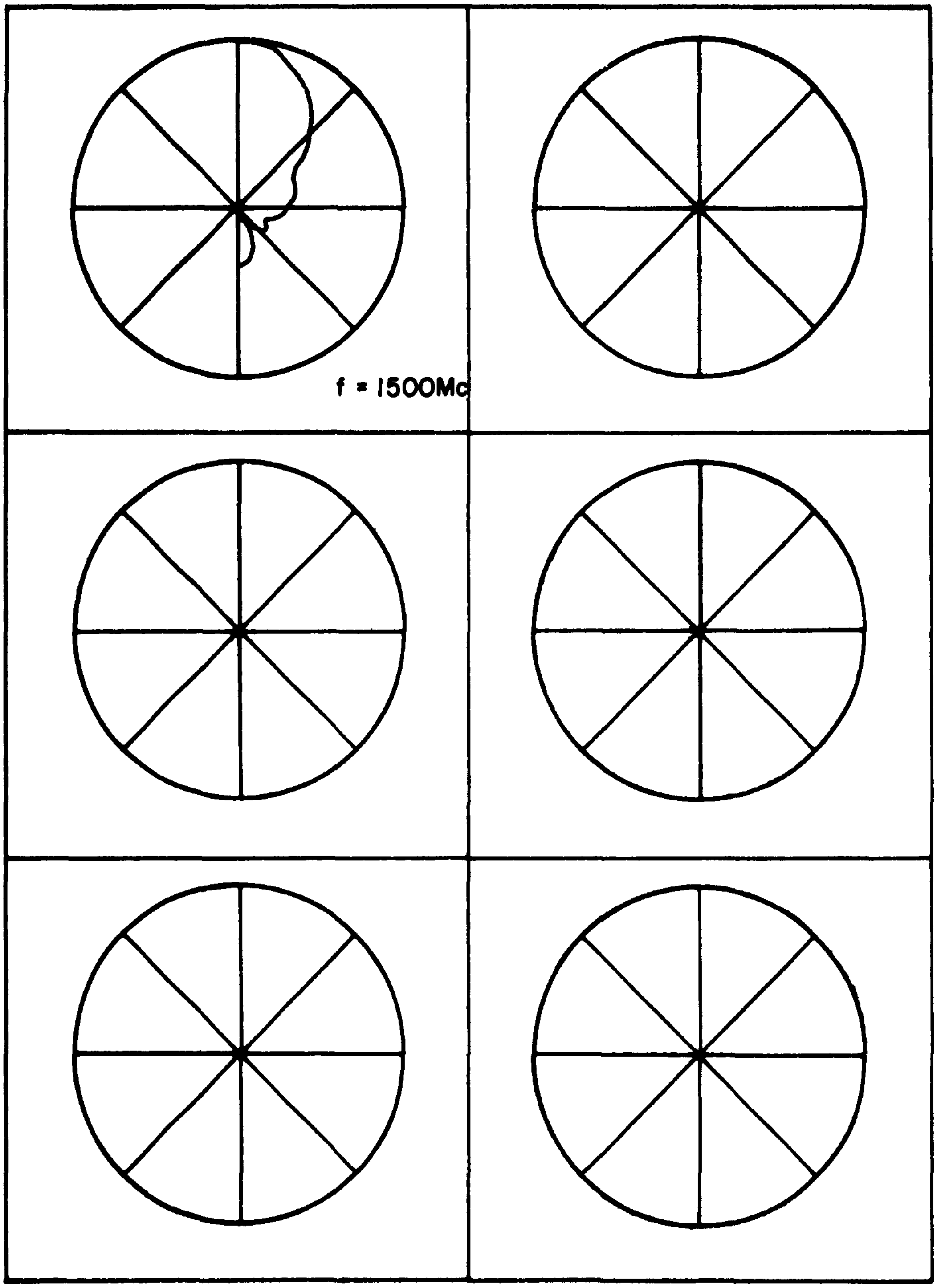
α = 9°



FAR - FIELD PATTERNS OF THE LOG - PERIODIC LETTER - RACK ANTENNA



FAR-FIELD PATTERN OF THE LOG-PERIODIC LETTER-RACK ANTENNA



TYPICAL FAR - FIELD PATTERN (E PLANE) OF

LP LETTER - RACK ANTENNA

that reported by Hurd[2] is carried out separately for the two regions I and II.

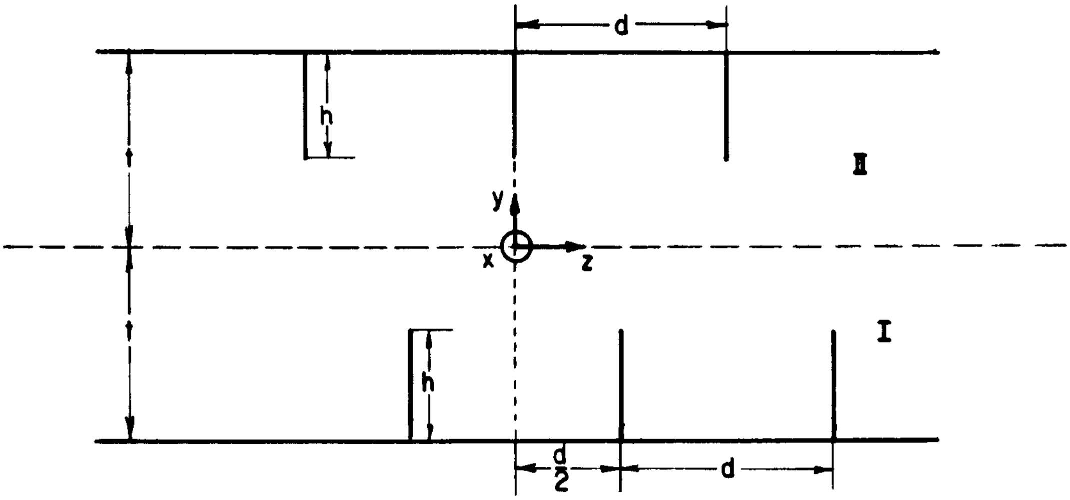


Figure 8.3. $\tau = 2(t - h)$

For the limiting case $t \longrightarrow \infty$ the expressions are the same as obtained by Hurd. For a finite t, the two equations for the two regions may be expressed as

$$\sum_{n=-\infty}^{\infty} \beta_n C_n \left(\frac{1}{\alpha_n - i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n + i\gamma_m} \right) - \beta_n C_n{}' \, e^{-\alpha_n \tau} \left(\frac{1}{\alpha_n + i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n - i\gamma_m} \right) = 0 \qquad (8.1)$$

and

$$\sum_{n=-\infty}^{\infty} \beta_n G_n \left(\frac{1}{\alpha_n - i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n + i\gamma_m} \right) - \beta_n G_n{}' \, e^{-\alpha_n \tau} \left(\frac{1}{\alpha_n + i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n - i\gamma_m} \right) = 0 \qquad (8.2)$$

$$m = 0, 1, 2, \ldots\ldots$$

C_n and G_n are the amplitudes of various space harmonics in regions I and II respectively. Primes on the coefficients denote the amplitude of the corresponding reflected waves due to the presence of the other surface. β_n and α_n are propagation constants in z and y direction for the nth harmonic outside the slot, whereas γ_m is the propagation constant for the mth mode inside the slots.

Establishing the continuity of electric and magnetic fields expressions of the two regions yields the two sets of equations

$$\sum_{n=-\infty}^{\infty} P_n \left(\frac{1}{\alpha_n - i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n + i\gamma_m} \right) - Q_n (-)^n e^{-\alpha_n \tau} \left(\frac{1}{\alpha_n + i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n - i\gamma_m} \right) = 0 \qquad (8.3a)$$

and

$$\sum_{n=-\infty}^{\infty} Q_n \left(\frac{1}{\alpha_n - i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n + i\gamma_m} \right) - P_n (-)^n e^{-\alpha_n \tau} \left(\frac{1}{\alpha_n + i\gamma_m} + \frac{e^{-i2\gamma_m h}}{\alpha_n - i\gamma_m} \right) = 0 \qquad (8.3b)$$

$$m = 0, 1, 2, \ldots\ldots$$

where P_n and Q_n are related to C_n, C_n', G_n, G_n', etc.

A study of the equation shows that if β_o is a solution for the propagation constant, $\beta_o + \frac{4n\pi}{d}$ is also a solution for any integer n. This has the implication that the effective period of the structure is d/2 and not d, the latter being the translational period.

The determinant of the set of Equations in (8.3) may be expanded as shown in Equation (8.4) under the following assumptions.

(a) The only propagating mode inside the slots is m = 0 and all other higher order modes are attenuating and hence $e^{-i2\gamma_m h}$ terms for $m \geqq 1$ are all considered negligible.

(b) Only α_o terms are considered in the expression $e^{-\alpha_n \tau}$. The determinantal equation for β is

$$\left(A + e^{-i2\gamma_o h}\right) - e^{-a_o\tau}\, e^{-2\frac{a_o d}{\pi}\log 2} \prod_{p=1}^{P} \frac{\left(1 - a_o/i\gamma_p\right)}{\left(1 + a_o/i\gamma_p\right)}$$

$$\prod_{p=1}^{P} \frac{(1 + a_o/a_p)(1 + a_o/\underline{a}_p)}{(1 - a_o/a_p)(1 - a_o/\underline{a}_p)} \left\{\left(\frac{a_o - i\gamma_o}{a_o + i\gamma_o}\right) A + e^{-i2\gamma_o h}\left(\frac{a_o + i\gamma_o}{a_o - i\gamma_o}\right)\right\} = 0 \tag{8.4}$$

where

$$A = \frac{a_o + i\gamma_o}{a_o - i\gamma_o}\, e^{-j\frac{kd}{\pi}\log 2}\, \mathrm{Exp}\left\{j\left[\sum_{p=1}^{P} - \arctan\left(\frac{k}{i\gamma_p}\right) + \arctan\left(\frac{k}{a_p}\right) + \arctan\left(\frac{k}{\underline{a}_p}\right)\right]\right\}.$$

The upper limit on infinite products and sums has been reduced to a finite value P by introducing the proper convergence factors.

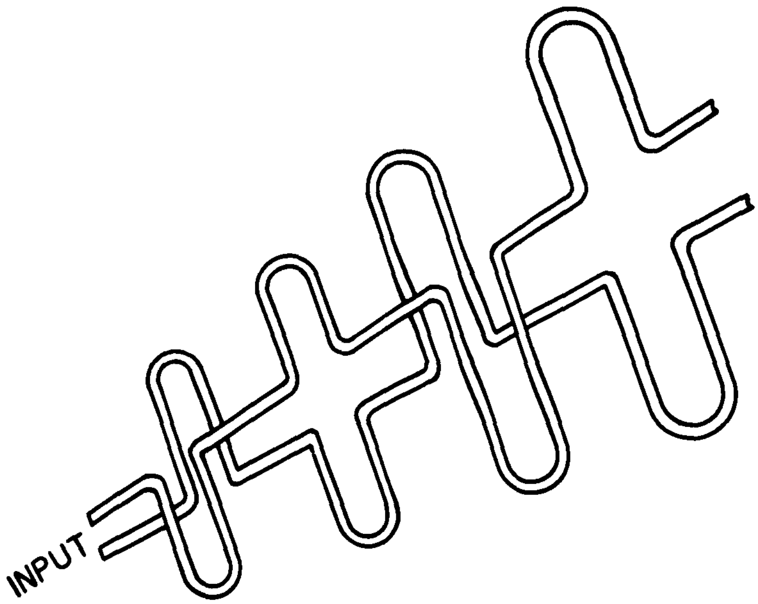
Equation (8.4) is presently being solved for β on IBM 7090 Digital Computer.

(d) Diffraction by Grating Structures

This work has been transferred into a different section in order to avoid duplication.

(e) Log-Periodic Folded Dipole Array

Based on the experience gained from the design of the Letter-Rack Antenna, we have used the series loaded transmission line idea to design a free space model of an antenna of LP design. The structure under consideration is shown in Figure 8.4. The patterns for this antenna look quite promising over the entire design range and preliminary input impedance measurements indicate that there is a good possibility of designing it to match a 300 ohm balanced line. Further impedance measurements are planned in the near future.



LOG-PERIODIC FOLDED DIPOLE ARRAY

(f) Log-Periodic Delta Array

We have designed a log-periodic Δ array over a ground plane, a schematic of which is shown in Figure 8.5.

This antenna also exhibits quite good pattern bandwidth. Further experimentation is planned for the future.

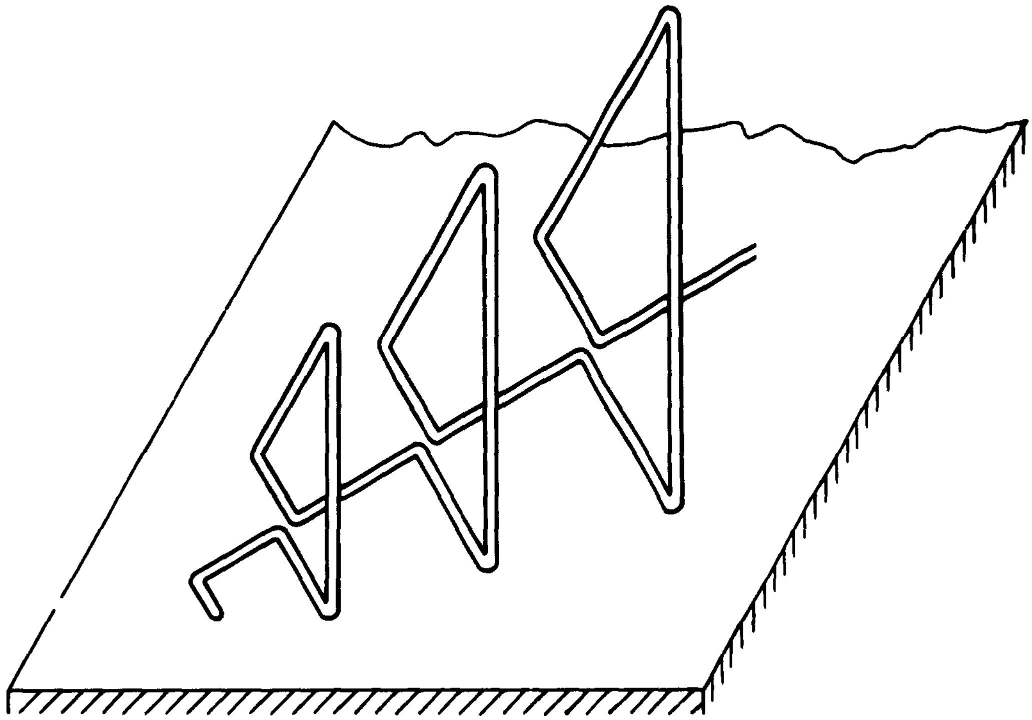


Figure 8.5. Log Periodic delta antenna

9. TRANSMISSION BETWEEN ANTENNAS WHEN THE FAR FIELD APPROXIMATION DOES NOT APPLY

9.1 Purpose

The purpose of this research is to determine the transmission coefficient between antennas located in their near fields.

9.2 Factual Data

9.2.1 Research Staff - J. R. Pace, G. A. Deschamps

9.2.2 Status

In the last quarterly period, a computer program was written for the IBM 7090 digital machine. This program was supposed to compute the power transfer between closely separated square apertures as a function of the angular orientation of the receiving aperture with respect to the sending aperture for various values of the separation. However, difficulties were encountered in running the program and as yet, not all of the desired computer results are available. The results for the special case of the apertures situated in parallel planes have been obtained and they are shown in Figure 9.1.

The specific expression for the transmission between closely spaced parallel square apertures can be derived by substituting the particular parameters describing these apertures into the expression for the generalized transmission coefficient reported earlier[3]. The angular function for a square aperture is given by

$$F(\theta,\phi) = \frac{\sin\left(\frac{\pi a}{\lambda} \cos \theta\right) \sin\left(\frac{\pi a}{\lambda} \sin \theta \sin \phi\right)}{\left(\frac{\pi a}{\lambda} \cos \theta\right) \left(\frac{\pi a}{\lambda} \sin \theta \sin \phi\right)}$$

This assumes a linearly polarized field. The proper coordinate system is illustrated in Figure . $F(\theta,\phi)$ and its derivatives are evaluated at $\theta = \pi/2$, $\phi = 0$ in the case of the sending aperture, and at $\theta = \pi/2$, $\phi = \pi$ radians in the case of the receiving aperture. The particular case where the two apertures are identical in size and aperture illumination was considered.

The resulting expression for t is given by

$$t = \frac{je^{-jkd}}{\lambda d} A_{1_{eff}} \left(1 + \frac{1}{2jkd} c_1 - \frac{1}{8k^2d^2} c_2\right)$$

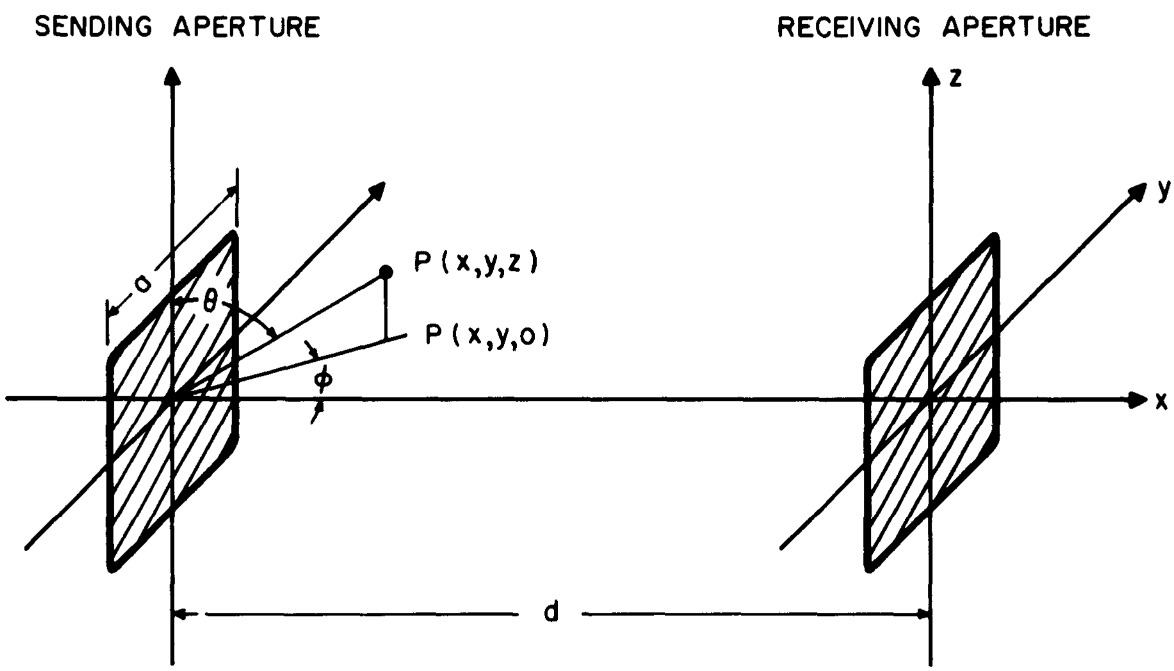


Figure 9.1

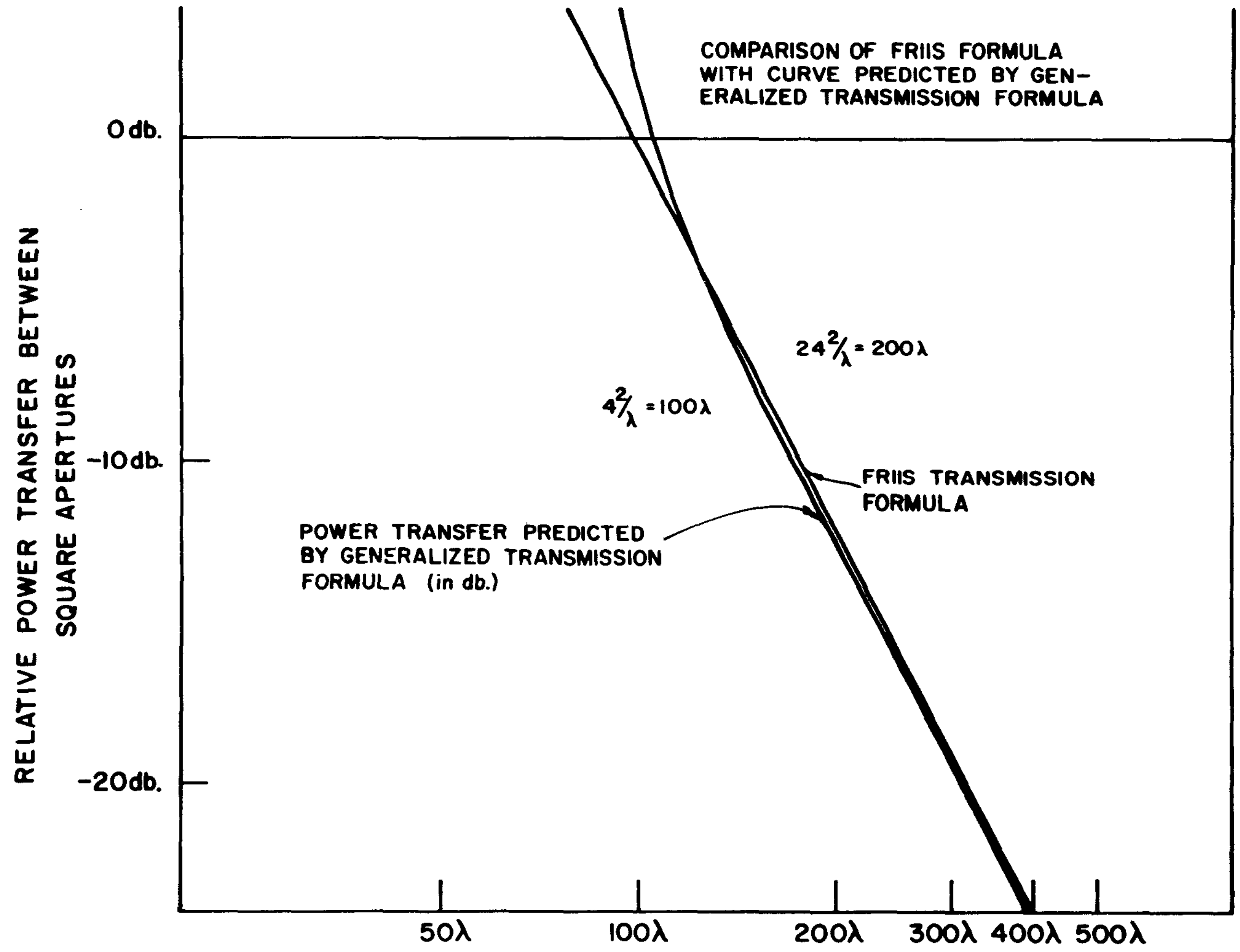


Figure 9.2. Separation between apertures in wavelengths.

where $A_{1_{eff}}$ is the effective area of either of the apertures,

λ is the operating wavelength,

$k = 2\pi/\lambda$

d is the distance between apertures in wavelengths, and

$$c_1 = -\frac{4}{3}\left(\frac{\pi a}{\lambda}\right)^2 = -\frac{4}{3}\alpha^2$$

$$c_2 = \frac{16}{3}\left(\frac{11}{15}\left(\frac{\pi a}{\lambda}\right)^4 + \left(\frac{\pi a}{\lambda}\right)^2\right)$$

$$= \frac{16}{3}\left(\frac{11}{15}\alpha^4 + \alpha^2\right)$$

Because α can be a large number, c_2 can be much greater than c_1. For smaller values of d, the third term contributes much to the value of t. The effect of computing higher order terms would be to cause the expression for t to blow up for even larger values of d. The expression for t, then, is invalid for small d. Actual computation shows that in the region where the expression is valid, the first term alone is sufficient to describe the power transfer (see Figure 8.2). The first term is just the usual far field transmission factor given by the Friis transmission formula. That the Friis transmission formula is valid for distances less than $2a^2/\lambda$ was already shown by Jacobs[4]. Jacobs' results are also valid for small separations. The results obtained from the generalized transmission coefficient do not compare favorably with those of Jacobs.

9.3 Plans for the Next Interval

The problem will be studied further, and a decision will be made whether to continue this line of research.

10. RADIATING LENS ILLUMINATED FROM A GOUBAU BEAM-WAVEGUIDE

10.1 Purpose

The purpose of this project is to determine the feasibility of developing a high resolution millimeter antenna by coupling from a Goubau beam-waveguide to a radiating lens.

10.2 Factual Data

10.2.1 Research Staff - P. E. Mast, J. F. Kauffman

M. Fournier, formerly associated with this project, has completed the requirements for the M.S.E.E. degree and has accepted permanent employment with the Canadian General Electric Company.

10.2.2 Status

The lens coupling system shown in Figure 10.1 to couple energy from a beam-waveguide to a radiating aperture has been constructed. The amplitude and phase correction lines were designed for operation at 70 Gc. using physical optics approximations. The diameter of the amplitude correction lens was 5.5 cm, the diameter of the phase correction lens was 19.2 cm, the dielectric constant of the polyfoam in these lenses was 1.6, and the spacing between them 25 cm.

The lowest mode on the beam-waveguide has fields which vary as $e^{-\alpha p^2}$. The amplitude correction lens was designed to spread the energy in beam-waveguide by a factor of 3.75. This Gaussian distribution of the field on the radiating lens gives a theoretical half-power beamwidth of 1.8°.

Measured radiation patterns are shown in Figure 10.2. The two patterns shown are for slightly different positions of the spreading lens. The measured half-power beamwidth agrees with the theoretical, but the side lobes are higher than expected. To prevent the measurement of many spurious side lobes due to direct illumination of the lens in the beam-waveguide and the spreading lens, it was necessary to shield the entire beam-waveguide and lens coupler.

10.2.3 Plans for the Next Interval

The mechanical arrangement for holding the various lenses will be refined to allow more precise mechanical adjustments. The present shielding of the beam-waveguide will be replaced by an absorbing shield.

There is a possibility that the side lobe levels presently obtained are due to the optical approximations made in the lens design. It is planned to obtain a more accurate lens design using a Fresnel approximation.

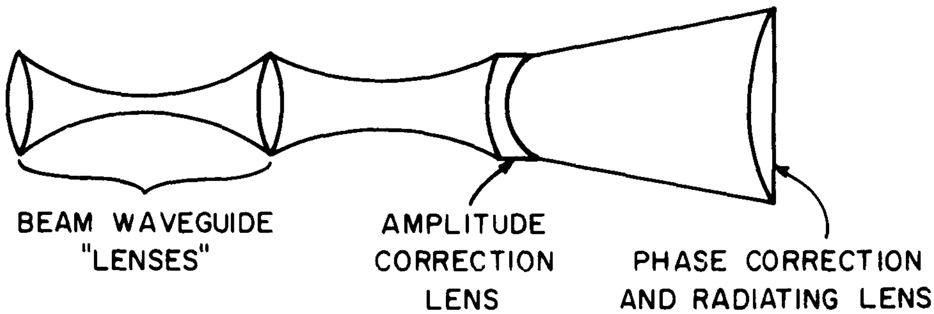


Figure 10.1. Amplitude and phase correction lenses illuminated by a beam waveguide.

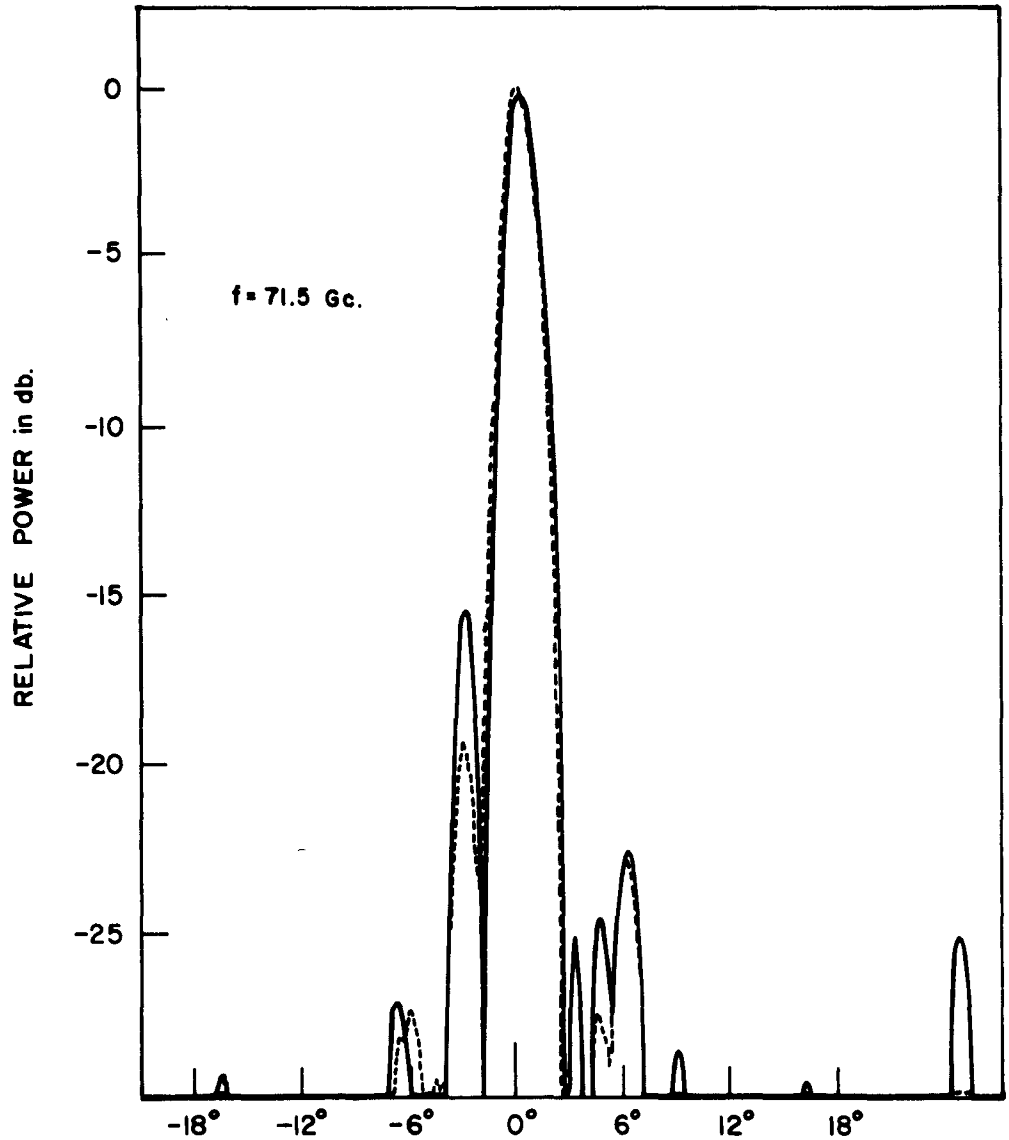


Figure 10.2. Radiation patterns of a lens coupler illuminated by a beam-waveguide.

11. ZONE PHASE PLATES

11.1 Purpose

The purpose of this project is to investigate the properties and uses of zone phase plates.

11.2 Factual Data

11.2.1 Research Staff - H. A. Shubert

11.2.2 Status

Computer calculations for the propagation constants of the modes in the dielectric slab region have been obtained for a wide range of parameters. Previous graphical analysis[5] has been essentially confirmed. The computer results have not yet been plotted in a suitable form but will appear in the next publication.

The computer results have, moreover, shown that an asymptotic form for the propagation constants of higher order cutoff modes is possible for general values of the parameters. This was not thought possible before.

For example, for equal sheet thickness and spacing, $\frac{W}{2}$ and for phase shift per section ϕ, the propagation constants shift one on each side of $\frac{N}{W}$ for the Nth mode, and are given by: (with N a positive integer)

$$|\tau_N| = \frac{N}{W} \pm \frac{1}{\pi W} \operatorname{Sin}^{-1} \left\{ \frac{2\sqrt{\kappa}}{\kappa + 1} \operatorname{Sin} \frac{\Phi}{2} \right\} + 0 \left[\frac{1}{N}\right] \tag{11.1}$$

$$\kappa = \begin{cases} \dfrac{\mu_2}{\mu_o}, & \text{for TE Modes} \\[2ex] \dfrac{E_2}{E_o}, & \text{for TM Modes} \end{cases} \tag{11.2}$$

Alternatively, with $\Phi = 2K\pi$, K integer, the dielectric sheet thickness $T = \frac{W}{2} + \Delta$, and the spacing $S = \frac{W}{2} - \Delta$; the asymptotic form of the propagation constants is:

$$|\tau_N| = \frac{N}{W} + \delta + 0 \left[\frac{1}{N}\right] \tag{11.3}$$

where δ is a shift on each side of $\frac{N}{W}$ and satisfies:

$$\delta = \pm \frac{1}{\pi W} \, \mathrm{Sin}^{-1} \left\{ \left[\frac{c-1}{c+1}\right] \mathrm{Sin}\left(\frac{2\pi N\Delta}{W} + 2\pi\delta\Delta\right) \right\} \tag{11.4}$$

and is generally given to the third decimal place by:

$$\delta = \pm \frac{1}{\pi W} \, \mathrm{Sin}^{-1} \left\{ \left[\frac{c-1}{c+1}\right] \mathrm{Sin}\left(\frac{2\pi N\Delta}{W}\right) \right\} \tag{11.5}$$

The above results are now being used to calculate the matrix elements in the mode matching problem at the phase plate-air interface.

11.3 Plans for the Next Interval

The matrix elements for the matching problem will be calculated and the convergence properties of the iterative solution investigated.

12. STUDY OF A CLASS OF GRATING PROBLEMS

12.1 Purpose

The purpose of this investigation is to study the diffraction properties of a class of uniform and modulated grating type structures. The Brillouin diagrams for these structures will be computed, and the scattering properties of the gratings in both the near and far field regions will be investigated.

12.2 Factual Data

12.2.1 Research Staff - J. R. Pace, R. Mittra

12.2.2 Status

In the previous report, this section was entitled, "Study of Focusing Properties of Metal-Lens Antennas". It was stated that a theoretical investigation of the fields around the focal point of a plano-elliptic metal plate lens would be made. However, the investigation showed that this was a very involved, though not impossible problem. Thus, it was considered desirable to study first a number of related problems, less complicated perhaps than the problem of the metal plate lens. Accordingly, the title of this section was changed.

A class of modulated structures will be studied. The basic geometry is the uniform, corrugated surface. This has been studied extensively and quite rigorously by a number of investigators. Among these are Brillouin[6], Carlson and Heins[7], Whitehead[8], and more recently, Hurd[2]. It has been solved rigorously by either solving a Weiner-Hopf equation or by solving by means of the Calculus of Residues an infinite set of linear algebraic equations. The solution to this problem has yielded information on the behavior of the propagation constant and the near fields of the structure. This structure has applications as a surface wave antenna.

Figure 12.1 The Basic Geometry - A Uniform Corrugated Surface.

A few examples of the way in which the structure can be modulated are illustrated below.

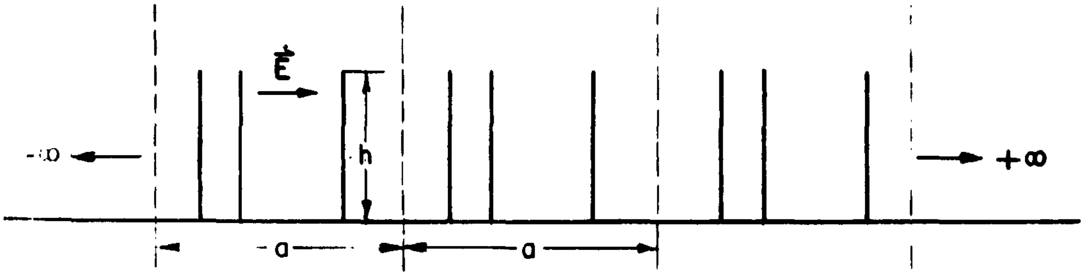


Figure 12.2 A Corrugated Surface with Non-Uniform Spacing Between Adjacent Plates.

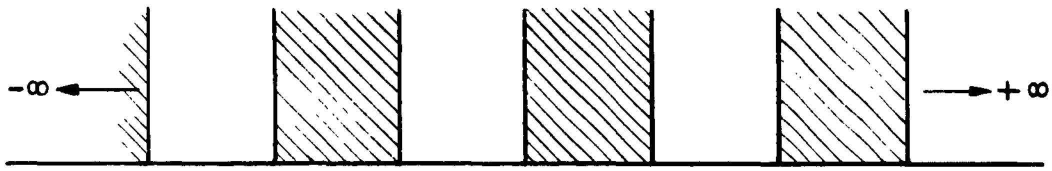


Figure 12.3 A Dielectric Loaded Corrugated Surface.

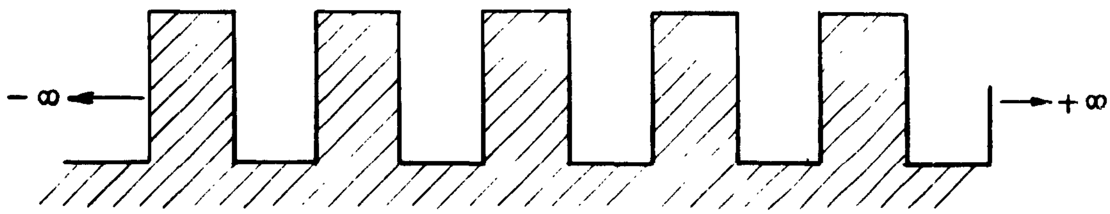
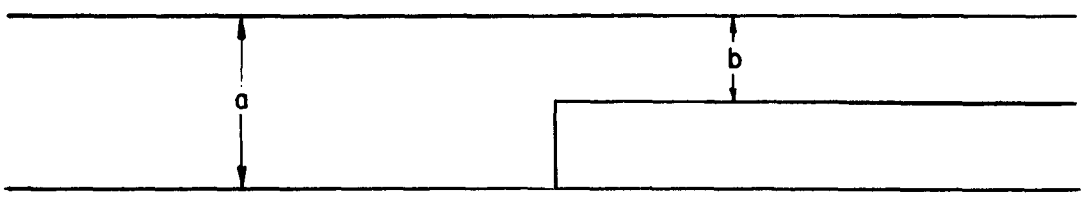


Figure 12.4 A Thick Corrugated Surface.

An investigation showed that the existing techniques are not readily applicable to the solution of these kind or problems. For instance, to formulate and solve the problem illustrated in Figure 12.2, directly in terms of Weiner-Hopf integrals equations, it would be necessary to solve a set of three coupled Weiner-Hopf equations. And mainly, to solve a Weiner-Hopf equation, the method of factorization is employed. Here the problem of factorization is a problem in factorizing a determinant rather than a simple expression. This proves to be quite formidable. Indeed, it is not certain that it is possible.

The problems illustrated in Figures 12.3 and 12.4 can be formulated in terms of a Weiner-Hopf equation. Williams[9] has formulated and solved the problem of the step discontinuity in a waveguide and has indicated that the bifuricated guide with one branch filled with dielectric can be solved. However, his formulation does not readily yield expressions for calculating the scattering properties and the Brillouin diagrams.



STEP DISCONTINUITY PROBLEM

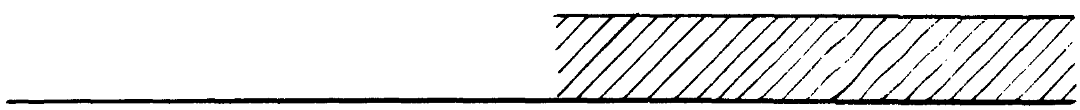


Figure 12.5 Dielectric Loaded Bifurication.

A new technique was needed to solve these problems and others of a similar nature. A technique has been developed and is being applied to these problems. This technique will be reported in detail in a forthcoming technical report. This technique facilitates the computation of the Brillouin diagram and the near fields.

12.3 Plans for the Next Interval

The Brillouin diagrams will be derived for the three structures illustrated above. Initially, their real roots will be calculated. Later, their complex roots, if any, will be calculated. If there are complex roots, these surfaces will have important applications as leaky wave antennas. In addition, the diffraction properties of these grating components of the surface wave structures will also be investigated.

REFERENCES

1. Watkins, D. A., Topic in Electromagnetic Theory, John Wiley & Sons, Inc., 1958, New York.

2. Hurd, R. A., "The Propagation of an Electromagnetic Wave Along an Infinite Corrugated Surface", Can. J. Phys., Vol. 32, pp. 727-734, Dec. 1954.

3. Quarterly Progress Report No. 4, "Research Studies on Problems Related to Antennas," Contract AF33(657)-8460, Section 12, p. 22, October, 1962.

4. Jacobs, E., "Predicting Power Transfer Between Large Apertures Antennas Closely Separated," IRE Trans. on Radio Frequency Interference, Vol. PRI-4, No. 3, pp. 23-40, October, 1962.

5. Quarterly Report No. 3 on contract AF33(658)-8460, dated 1 July 1962, University of Illinois, Antenna Laboratory, p. 32.

6. Brillouin, L., "Waveguides for Slow Waves," Journal of Applied Physics, Vol. 19, pp. 1023-1041, November, 1948.

7. Carlson, J. F. and Hains, A. E., "The Reflection of an Electromagnetic Wave by an Infinite Set of Plates," Quarterly of Applied Mathematics, Vol. 4, pp. 313-329, January, 1947.

8. Whitehead, E. A. N., "The Theory of Parallel Plate Media for Microwave Lenses," Proc. IEE (London), Vol. 98, Part III, pp. 133-140, January, 1951.

9. Williams, W. E., "Step Discontinuites in Waveguides," Res. Rep. No. EM-77, Institute of Mathematical Science, New York University, New York, N. Y., April, 1955.

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TECHNICAL REPORTS AND MEMORANDA ISSUED

Contract AF33(616)-310

"Synthesis of Aperture Antennas," Technical Report No. 1, C. T. A. Johnk, October, 1954.*

"A Synthesis Method for Broadband Antenna Impedance Matching Networks," Technical Report No. 2, Nicholas Yaru, 1 February 1955. * AD 61049.

"The Assymmetrically Excited Spherical Antenna," Technical Report No. 3, Robert C. Hansen, 30 April 1955.*

"Analysis of an Airborne Homing System," Technical Report No. 4, Paul E. Mayes, 1 June 1955 (CONFIDENTIAL).

"Coupling of Antenna Elements to a Circular Surface Waveguide," Technical Report No. 5, H. E. King and R. H. DuHamel, 30 June 1955.*

"Input Impedance of A Spherical Ferrite Antenna with A Latitudinal Current," Technical Report No. 6, W. L. Weeks, 20 August 1955.

"Axially Excited Surface Wave Antennas," Technical Report No. 7, D. E. Royal, 10 October 1955.*

"Homing Antennas for the F-86F Aircraft (450-2500 mc), Technical Report No. 8, P. E. Mayes, R. F. Hyneman, and R. C. Becker, 20 February 1957, (CONFIDENTIAL).

"Ground Screen Pattern Range," Technical Memorandum No. 1, Roger R. Trapp, [illegible] July 1955.*

Contract AF33(616)-3220

"Effective Permeability of Spheriodal Shells," Technical Report No. 9, E. J. Scott and R. H. DuHamel, 16 April 1956.

"An Analytical Study of Spaced Loop ADF Antenna Systems," Technical Report No. 10, D. G. Berry and J. B. Kreer, 10 May 1956. AD 98615.

"A Technique for Controlling the Radiation from Dielectric Rod Waveguides," Technical Report No. 11, J. W. Duncan and R. H. DuHamel, 15 July 1956.*

"Direction Characteristics of a U-Shaped Slot Antenna," Technical Report No. 12, Richard C. Becker, 30 September 1956.**

"Impedance of Ferrite Loop Antennas," Technical Report No. 13, V. H. Rumsey and W. L. Weeks, 15 October 1956. AD 119780.

"Closely Spaced Transverse Slots in Rectangular Waveguide," Technical Report No. 14, Richard F. Hyneman, 20 December 1956.

"Distributed Coupling to Surface Wave Antennas," Technical Report No. 15, R. R. Hodges, Jr., 5 January 1957.

"The Characteristic Impedance of the Fin Antenna of Infinite Length," Technical Report No. 16, Robert L. Carrel, 15 January 1957.*

"On the Estimation of Ferrite Loop Antenna Impedance," Technical Report No. 17, Walter L. Weeks, 10 April 1957.* AD 143989.

"A Note Concerning a Mechanical Scanning System for a Flush Mounted Line Source Antenna," Technical Report No. 18, Walter L. Weeks, 20 April 1957.

"Broadband Logarithmically Periodic Antenna Structures," Technical Report No. 19, R. H. DuHamel and D. E. Isbell, 1 May 1957. AD 140734.

"Frequency Independent Antennas," Technical Report No. 20, V. H. Rumsey, 25 October 1957.

"The Equiangular Spiral Antenna," Technical Report No. 21, J. D. Dyson, 15 September 1957. AD 145019.

"Experimental Investigation of the Conical Spiral Antenna," Technical Report No. 22, R. L. Carrel, 25 May 1957.** AD 144021.

"Coupling between a Parallel Plate Waveguide and a Surface Waveguide," Technical Report No. 23, E. J. Scott, 10 August 1957.

"Launching Efficiency of Wires and Slots for a Dielectric Rod Waveguide," Technical Report No. 24, J. W. Duncan and R. H. DuHamel, August 1957.

"The Characteristic Impedance of an Infinite Biconical Antenna of Arbitrary Cross Section," Technical Report No. 25, Robert L. Carrel, August 1957.

"Cavity-Backed Slot Antennas," Technical Report No. 26, R. J. Tector, 30 October 1957.

"Coupled Waveguide Excitation of Traveling Wave Slot Antennas," Technical Report No. 27, W. L. Weeks, 1 December 1957.

"Phase Velocities in Rectangular Waveguide Partially Filled with Dielectric," Technical Report No. 28, W. L. Weeks, 20 December 1957.

"Measuring the Capacitance per Unit Length of Biconical Structures of Arbitrary Cross Section," Technical Report No. 29, J. D. Dyson, 10 January 1958.

"Non-Planar Logarithmically Periodic Antenna Structure", Technical Report No. 30, D. E. Isbell, 20 February 1958. AD 156203.

"Electromagnetic Fields in Rectangular Slots," Technical Report No. 31, N. J. Kuhn and P. E. Mast, 10 March 1958.

"The Efficiency of Excitation of a Surface Wave on a Dielectric Cylinder," Technical Report No. 32, J. W. Duncan, 25 May 1958.

"A Unidirectional Equiangular Spiral Antenna," Technical Report No. 33, J. D. Dyson, 10 July 1958. AD 201138.

"Dielectric Coated Spheroidal Radiators," Technical Report No. 34, W. L. Weeks, 12 September 1958. AD 204547.

"A Theoretical Study of the Equiangular Spiral Antenna," Technical Report No. 35, P. E. Mast, 12 September 1958. AD 204548.

Contract AF33(616)-6079

"Use of Coupled Waveguides in a Traveling Wave Scanning Antenna," Technical Report No. 36, R. H. MacPhie, 30 April 1959. AD 215558.

"On the Solution of a Class of Wiener-Hopf Integral Equations in Finite and Infinite Ranges," Technical Report No. 37, R. Mittra, 15 May 1959.

"Prolate Spheriodal Wave Functions for Electromagnetic Theory," Technical Report No. 38, W. L. Weeks, 5 June 1959.

"Log Periodic Dipole Arrays," Technical Report No. 39, D. E. Isbell, 1 June 1959. AD 220651.

"A Study of the Coma-Corrected Zoned Mirror by Diffraction Theory," Technical Report No. 40, S. Dasgupta and Y. T. Lo, 17 July 1959.

"The Radiation Pattern of a Dipole on a Finite Dielectric Sheet," Technical Report No. 41, K. G. Balmain, 1 August 1959.

"The Finite Range Wiener-Hopf Integral Equation and a Boundary Value Problem in a Waveguide," Technical Report No. 42, R. Mittra, 1 October 1959.

"Impedance Properties of Complementary Multiterminal Planar Structures," Technical Report No. 43, G. A. Deschamps, 11 November 1959.

"On the Synthesis of Strip Sources," Technical Report No. 44, R. Mittra, 4 December 1959.

"Numerical Analysis of the Eigenvalue Problem of Waves in Cylindrical Wave-guides, Technical Report No. 45, C. H. Tang and Y. T. Lo, 11 March 1960.

"New Circularly Polarized Frequency Independent Antennas with Conical Beam or Omnidirectional Patterns," Technical Report No. 46, J. D. Dyson and P. E. Mayes, 20 June 1960. AD 241321.

"Logarithmically Periodic Resonant-V Arrays," Technical Report No. 47, P. E. Mayes and R. L. Carrel, 15 July 1960. AD 246302.

"A Study of Chromatic Aberration of a Coma-Corrected Zoned Mirror," Technical Report No. 48, Y. T. Lo, June 1960.

"Evaluation of Cross-Correlation Methods in the Utilization of Antenna Systems," Technical Report No. 49, R. H. MacPhie, 25 January 1961

"Synthesis of Antenna Products Patterns Obtained from a Single Array," Technical Report No. 50, R. H. MacPhie, 25 January 1961.

"On the Solution of a Class of Dual Integral Equations," Technical Report No. 51, R. Mittra, 1 October 1961. AD 264557.

"Analysis and Design of the Log-Periodic Dipole Antenna," Technical Report No. 52, Robert L. Carrel, 1 October 1961. AD 264558.

"A Study of the Non-Uniform Convergence of the Inverse of a Doubly-Infinite Matrix Associated with a Boundary Value Problem in a Waveguide," Technical Report No. 53, R. Mittra, 1 October 1961. AD 264556.

Contract AF33(616)-8460

"The Coupling and Mutual Impedance Between Balanced Wire-Arm Conical Log-Spiral Antennas," Technical Report No. 54, J. D. Dyson, June 1962.

"An Investigation of the Near Fields on the Conical Equiangular Spiral Antenna," Technical Report No. 55, O. L. McClelland, May 1962.

"Input Impedance of Some Curved Wire Antennas," Technical Report No. 56, C. H. Tang, June 1962.

"Polygonal Spiral Antennas," Technical Report No. 57, C. H. Tang. O. L. McClelland, June 1962.

"On Increasing the Effective Aperture of Antennas by Data Processing," Technical Report No. 58, R. H. MacPhie, July 1962.

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"Backward Wave Radiation from Periodic Structures and Application to the Design of Frequency-Independent Antennas," Technical Report No. 60, P. E. Mayes, G. A. Deschamps, and W. T. Patton, December 1962.

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"On the Mapping by a Cross-Correlation Antenna System of Partially Coherent Radio Sources," Technical Report No. 62, R. H. MacPhie, October 1962.

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